UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

Thos. H. MacDonald, Chief

Division of Agricultural Engineering,

S. E. McCrory, Chief.

SOME ASPECTS OF DRAINAGE

in

THE TERRITORY OF HAWAII

by

R. A. Hart, Senior Drainage Engineer.

Prepared under the direction of

Samuel Fortier

Associate Chief, Division of Agricultural Engineering

July 1923.

TABLE OF CONTENTS

SUMMARY.

Economic conditions in the Territory of Hawaii demand that the available arable acreage be made to produce at the highest feasible rate; that, so far as possible, extension of the acreage devoted to pineapple growing shall not be at the expense of the sugar cane acreage, and that lands, formerly devoted to the commercial production of rice, be put into a sugar-cane producing condition wherever practicable.

The Territory is blessed with a moderate and equable temperature but the mean annual temperature is only a few degrees above that at which the growth of sugar cane is practically dormant. Unsatisfactory production has been attained in certain relatively high fields where the mean temperature is low and the precipitation is excessive.

Precipitation is extremely variable throughout the Territory and almost every possible degree of aridity and humidity is presented. Precipitation within the arable area is not so variable but even here a range of from about 20 inches per annum to over 200 inches per annum is recorded. Very heavy storms have been experienced throughout the arable area.

On some of the plantations the amount and distribution of the annual rainfall are such that sugar cane may be grown successfully without irrigation, but on the islands of Kauai, Oahu and Maui, a large proportion of the area devoted to the growing of sugar cane is under irrigation, due either to deficiency in, or improper distribution of, the annual precipitation.

A very low duty of water is in vogue generally, and it follows that excessive amounts of water are applied, either naturally or artificially, throughout the sugar cane area.

Many Hawaiian soils possess a remarkably high water holding capacity and the natural surface and under-drainage generally is good, but in spite of these favorable factors the need for artificial drainage has become apparent. Moreover, the relation between high soil moisture content and low soil temperature makes it desirable to expediate the removal of water from the soil pores and, in some instances, to prevent excessive amounts of water from entering the capillary spaces.

Areas formerly devoted to the culture of rice are usually low-lying and have a high water table. Artificial drainage is essential to their conversion into a condition suitable for the growing of non-aquatic plants.

Aritificial drainage of Hawaiian soils is feasible and the economic conditions are such as to warrant expenditures somewhat greater than under mainland conditions. Both surface drainage and under-drainage will be required. Both open drains and covered drains will be employed. Much drainage may be effected by gravity but some of the areas involved are so low that pumping will be required. Tidal variations are so slight that tide-gate control rarely will be feasible.

The benefits that will accrue from the installation of artificial drainage systems are many and are set forth in detail in this report. The process of drainage reclamation is explained, and methods and devices are described. The use of saline water in irrigation and its relation to the subsequent treatment of drained soils are discussed.

It is recommended that serious consideration be given to the possibilities of artificial drainage in the general scheme of Hawaiian agriculture; that needed investigations of the interrelated factors be undertaken, and that active steps be taken toward actual reclamation and improvement wherever expedient.

INTRODUCTORY

On April 15, 1922, a request was received by the writer from Mr. Antoine R. Ivins, Manager of the Laie Plantation at Laie, and of the Koolau Agricultural Co., Ltd., of Hauula, Oahu, for assistance in the solution of the drainage problems of these plantations.

Later Mr. J. T. Waterhouse of Alexander and Baldwin, Ltd., Factors, of Honolulu, Oahu, made a more formal request for such aid as this Bureau might render in a study of the drainage needs of the sugar plantations of the Territory of Hawaii.

This request was followed by correspondence between Mr. H. P. Agee, Director of the Experiment Station of the Hawaiian Sugar Planters Association, and Dr. Samuel Fortier, Associate Chief of the Division of Agricultural Engineering, of the U. S. Department of Agriculture, which culminated in a formal agreement that the writer should be detailed to make an investigation of the drainage needs of a number of the member plantations, the salary involved to be paid by the Department and the expenses incurred to be paid by the plantations.

In accordance with this agreement the writer left Salt Lake City, on January 7, 1923 and returned on March 24, 1923, the period from January 16 to March 14 being spent in the Territory.

General ovservations were made on the islands of Hawaii, Maui, Oahu and Kauai and more or less detailed investigations were conducted on the following plantations;

Laie Plantation, Laie, Oahu.
Koolau Agricultural Co., Ltd., Hauula, Oahu.
Kahuku Plantation Co., Kahuku, Oahu.
Ewa Plantation Co., Ewa, Oahu.
Makee Sugar Co., Kealia, Kauai.
Koloa Sugar Co., Koloa, Kauai.
Kekaha Sugar Co., Kekaha, Kauai.
Olaa Sugar Co., Ltd., Olaa, Hawaii.

Climatological and tide data were obtained from the Honolulu office of the U. S. Weather Bureau. Profile data were obtained from the records of the Oahu Railway and Land Company. Information and maps were obtained from the office of the Territorial Surveyor.

Reports and bulletins were obtained from the U. S. Department of Agriculture Experiment Station and several conferences were had with Director J. M. Westgate and members of his staff.

Records, texts, reports and bulletins in the office of the experiment Station of the Hawaiian Sugar Planters Association were studied in detail and numerous conferences were had with Director H. P. Agee and members of his staff.

Documents, data and information were obtained from many other sources and the heartiest cooperation was extended by interested and disinterested persons alike.

To all those who so cooperated, grateful appreciation is hereby expressed for the valuable contributions to the sum total of the information obtained.

This report is intended to present the general aspect of drainage in the Territory with special reference to the problems presented on the plantations to which reference has already been made.

Separate appendices are presented, each presenting in some detail the specific problems of the plantation under consideration, together with suggestions and recommendations as to the solution of the problems.

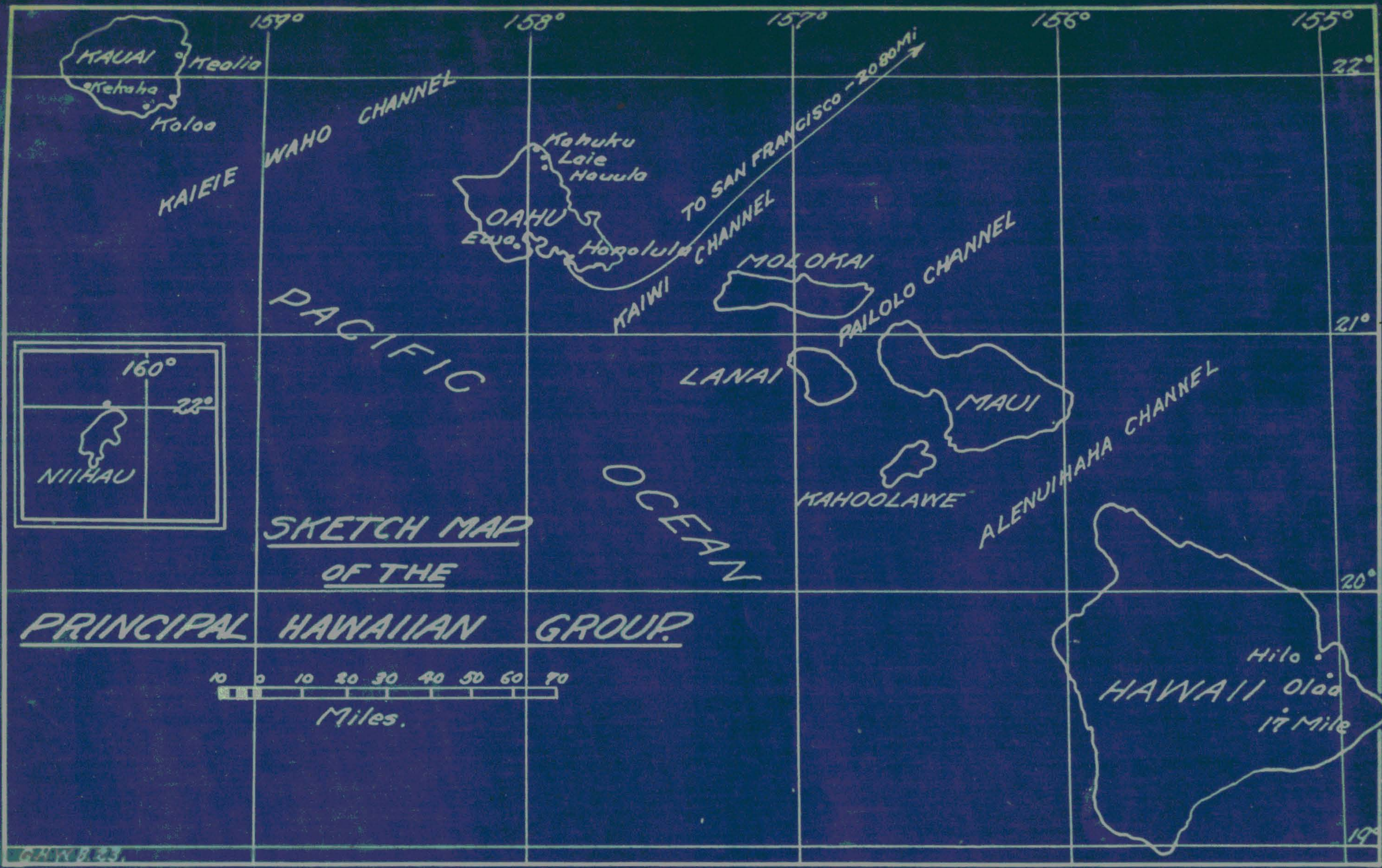
It is not intended that the report shall be final word on the subject. Indeed, in some instances, the best that can be done is to suggest rather complex and detailed experimental operations for the further study of existing conditions, and in all cases, such suggestions and recommendations as are made are predicated upon further detailed engineering and investigational word. The report, then, is preliminary in character, and if a stable foundation is laid for consistent investigational and developement work, the purpose of the writer will be attained.

FACTORS RELATING TO NEED FOR DRAINAGE.

GEOGRAPHICAL LOCATION.

The Territory of Hawaii comprises a group of eight inhabited, and a number of uninhabited, islands lying largely between 18° 56' and 22° 14' north latitude and between 154° 47' and 160° 16' west longitude. Honolulu, the capital city and chief port is situated 2080 sea miles southwest of San Francisco, which is the nearest continental port. Land nearer than the west coast of the mainland is represented by more or less unimportant islands of the Pacific. This marked isolation has a bearing on the drainage problem climatically and economically.

The chief islands of the group lie practically along a line about 380 miles long extending from the northwest to the southeast as may be seen by the accompanying sketch map (Fig. 1) but notwithstanding the great expanse of territory involved, the actual land area is only about 6650 square miles, 4210 squ are miles of which is represented by the


159°
158°
157°
156°
155°
22°
21°
20°
19°
KAUAI
Keolia
Kekaha
Koloa
KAIEIE WAHO CHANNEL
Kahuku
Laie
Hauula
OAHU
Ewa
Honolulu
TO SAN FRANCISCO - 2080 Mi
KAIWI CHANNEL
MOLOKAI
PAILOLO CHANNEL
PACIFIC
OCEAN
LANAI
MAUI
KAHOOLAWE
ALENUIHAHA CHANNEL
160°
22°
NIIHAU
SKETCH MAP
OF THE
PRINCIPAL HAWAIIAN GROUP.
10 0 10 20 30 40 50 60 70
Miles.
Hilo
Olaa
17 Mile
HAWAII
G.H.W. 8.23.

island of Hawaii, with the areas of the other members of the group rated as follows: Maui 728, Oahu, 600, Kauai 547, Molokai 261, Lanai 139, Niihau 97, Kahoolawe 69.

The several islands are thus separated one from another by channels ranging up to 63 miles in width. Conditions on one island of the group may, therefore, bear little relation to those on another island.

It might appear that conditions would be quite uniform on any one island, with the possible exception of Hawaii, due to their small area, but such is not the case as will be pointed out hereafter.

GEOLOGY OF FORMATION.

Geologically speaking the Hawaiian group consists of a chain of volcanoes, rising from the sea bed, at a depth of from 15000 to 20000 feet, to a maximum height of nearly 14000 feet above sea level. Mauna Loa and its contemporary Kilauea are located at the southeast extremity of the chain, and are still active, but as one progresses toward the northwest it is seen that the volcanoes generally are successively older. In some cases a single volcano constitutes an island. Maui is a doublet with Puu Kukui on west Maui geologically much older than Halelakala on east Maui. Hawaii comprises five volcanoes built one upon another. Oahu comprises two ranges of volcanoes with a relatively high plateau between.

The actual ages of the several volcanoes is a matter of speculation but it is sufficient for the purposes of this report to point out that, in general, the islands are still young enough that erosion has not developed to an extended degree and that in consequence, the soils are largely residual in character. Erosion and coloring are most noticeable on the island of Kauai, on west Maui and on the windward

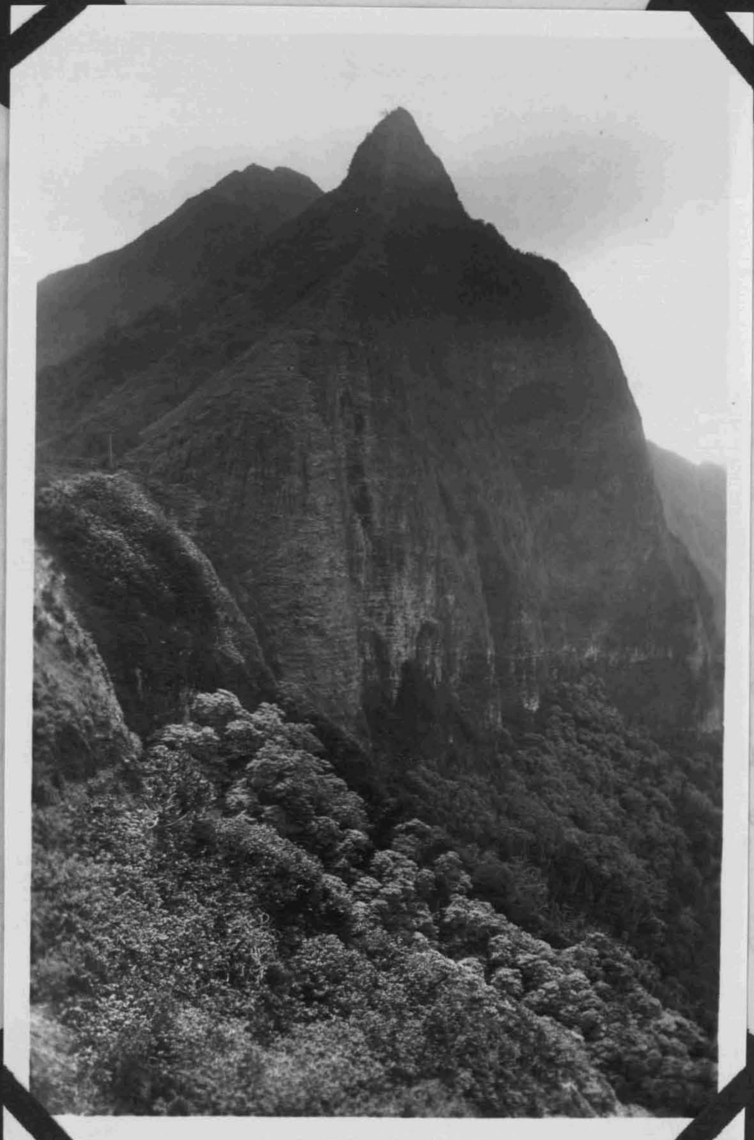


Fig. 2.

Showing Precipitous Mountain Barrier with Steep Slope at Foot.

side of the Kohala Hills on Hawaii. Waimea canyon and Olokele canyon on Kauai and Iao valley on Maui are the best examples of well developed erosion. The absence of perennial streams is one of the most noticeable features of the Territory.

TOPOGRAPHY.

The altitude of the highest points on the several islands ranges from about 1300 feet to nearly 14000 feet above the sea level but since the ratios of such elevations to the lengths of average profiles across the respective islands are comparable, some more or less general statements may be made as to the configuration and its effect upon climatological conditions, hence upon agricultural practices, including drainage.

In general the mountain peaks are rugged and bold and the windward slopes are more or less precipitous, leaving but a narrow belt of arable land near the sea and relatively near sea level. (See Figs. 2 & 3). The leeward slopes are frequently less precipitous and the arable belt is wider and extends to a somewhat higher elevation. In some cases the windward slopes are supplanted by almost vertical precipices called palis as on Oahu and Molokai which rise hundreds of feet, sheer above the arable area. (see Fig. 4.)

In other cases the lava flows have pushed out to the water's edge leaving no beach and presenting an insurmountable precipitous barrier, as on windward Hawaii, at Hanalei, Kauai and elsewhere. On the other hand more or less gentle slppes may be presented as at Olaa, Hawaii, permitting agriculture to be practiced up to an elevation of, perhaps, 1800 feet. Variations on the leeward side are also found as, for example, the precipitous promontories of the Waianae Range on Oahu and the impassable western extremity of Kauai. Oahu also presents a variation, in the plateau formed by the conjunction of the Waianae and Koolau Ranges, while an isthmus connects east and west Maui.

Longitudinal profiles are rough and uneven in the extreme and windward slopes particularly abount in steep ravines having rather abrupt side slopes. Transverse profiles generally present flattening grades as one descends from mountain peak to sea shore but this is often varied by coral reef formations at and near the water's edge, in which case land some little distance inland has an elevation a little lower than that of the reef formations.

Areas near the sea are cut up by bays, lochs, inlets, gullies, and channels of more or less intermittent streams. Small valleys extend back into the mountain masses and from these radiate gulches, ravines and clefts.

CLIMATOLOGICAL ASPECTS.

The Hawaiian group lies entirely within the tropics but true tropical conditions do not obtain either with respect to climatological conditions or to vegetation.

Temperatures.

Temperatures are moderate and equable. The mean annual temperature for all stations on all islands, as indicated by the U. S. Weather Bureau records covering the period 1905 to 1921 inclusive, is 71.5° F. The highest temperature recorded at any station during the period was 98° F. and the lowest was 25° F. These figures are exceptional, however, as is indicated in the following tables;

Fig. 3.

Showing Relatively Narrow Belt of Arable Lands

(The seashore is but a few feet in the rear)

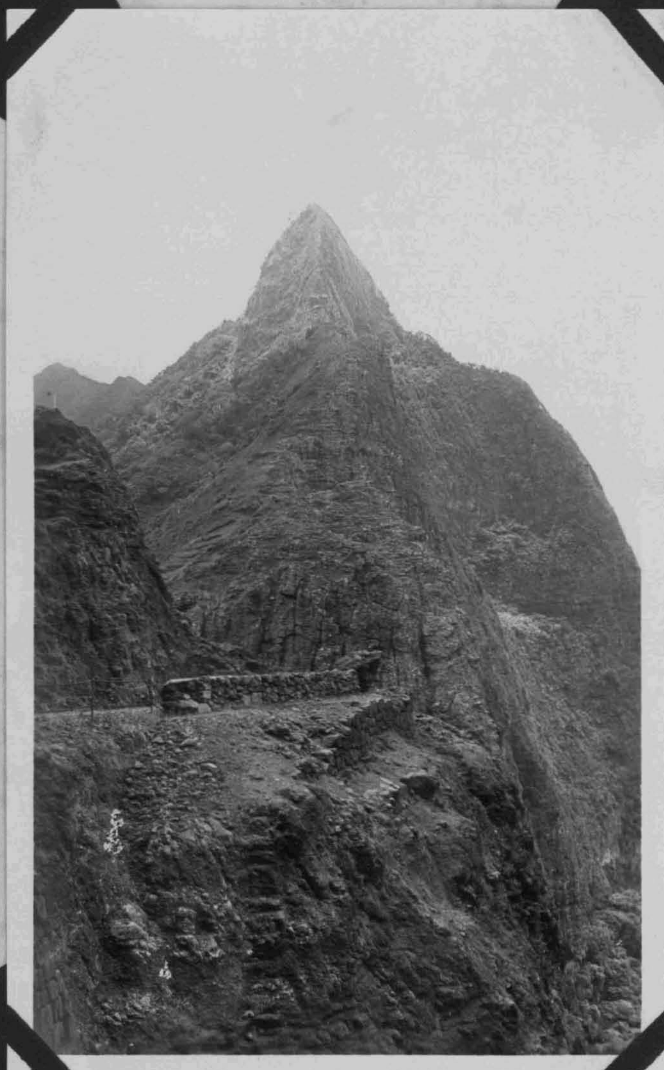


Fig. 4.

Showing a Characteristic Pali Formation.

TABLE 1.

NO. of STATIONS	ISLANDS	MEAN ELEV.	WARMEST MONTH	MEAN	COLDEST MONTH	MEAN	ANNUAL MEAN
23	Hawaii	1339'	Aug.	71.6°	Feb.	66.4°	69.0°
6	Kauai	161'	Aug.	77.1°	Jan.	69.2°	73.4°
1	Lanai	1780'	Aug.	71.1°	Feb.	64.7°	68.0°
12	Maui	859'	Sep.	73.3°	Feb.	67.2°	70.2°
3	Molokai	313'	Aug.	76.8°	Feb.	69.6°	73.2°
19	Oahu	353'	Aug.	76.7°	Jan.	69.3°	73.1°

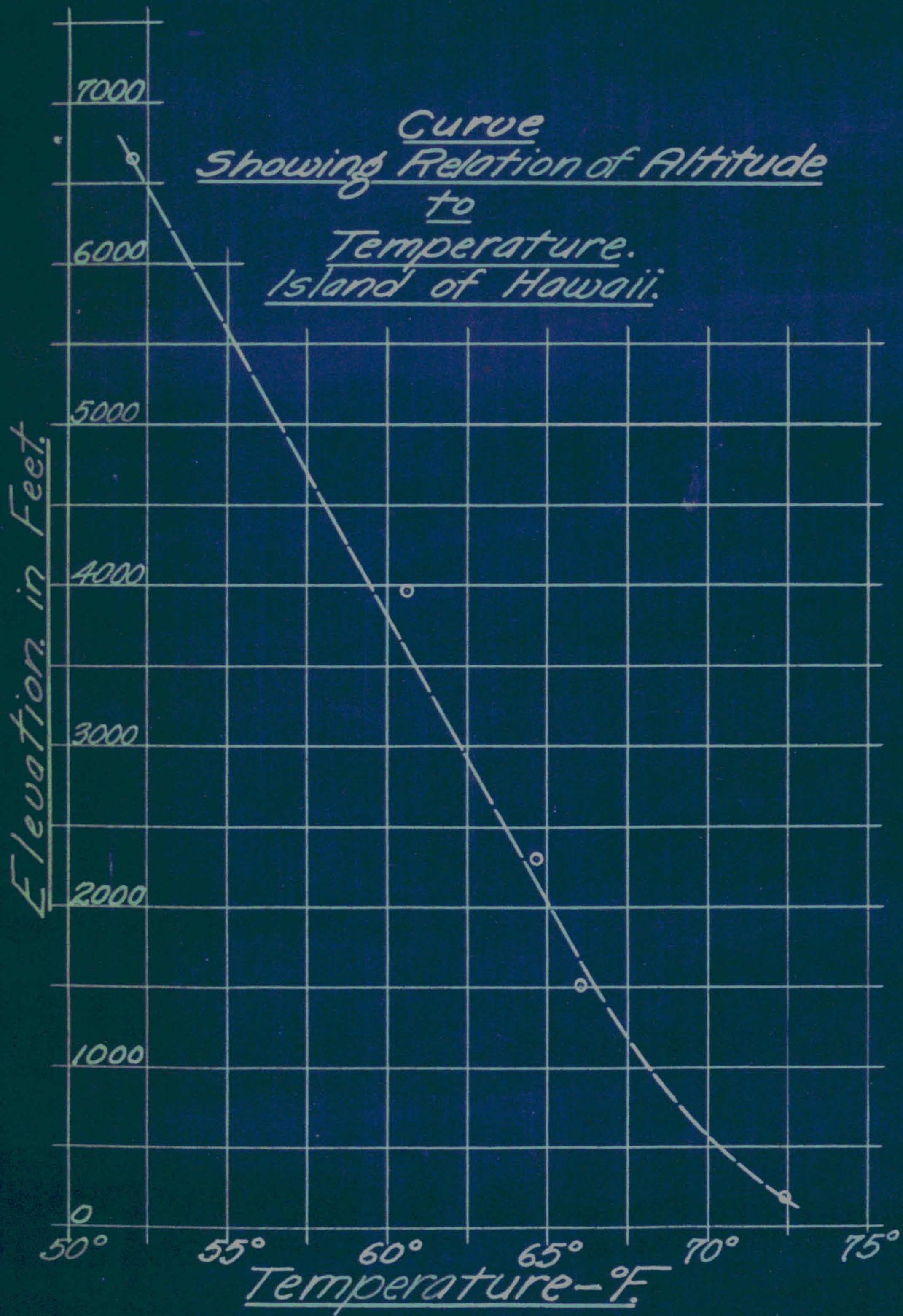
TABLE 2.

ISLAND	EXTREME HIGHEST	ELEV.	EXTREME LOWEST	ELEV.
Hawaii	98°	11'	25°	6685'
Kauai	93°	14'	44°	14'
Lanai	87°	1780'	49°	1780'
Maui	95°	1700'	43°	1700'
Molokai	94°	800'	48°	70'
Oahu	97°	30'	41°	990'

It will be noted that the extreme lowest temperature was recorded at a station having an elevation of 6685' and therefore is of no importance to the present investigation. The mean of the other extreme lowest figures is 45° F., while the mean of the extreme highest figures if 94°, the variation being 49° F.

The mean of means for the warmest months is 74.4° and of the coldest months is 67.7° F., the variation being only 6.7° F.

Temperatures vary with the altitudes bearing a somewhat inverse ratio as may be seen from the following table of annual mean temperatures for certain stations on the island of Hawaii.



Curve
Showing Relation of Altitude
to
Temperature.
Island of Hawaii.
Elevation in Feet.
7000
6000
5000
4000
3000
2000
1000
0
50°
55°
60°
65°
70°
75°
Temperature-°F.

G.H.W.B. 27.

TABLE 3.

STATION	ELEVATION	ANNUAL MEAN
Olaa Mill	210'	72.5°
Mountain View x	1530'	66.1°
Glenwood	2300'	64.7°
Volcano	3984'	60.6°
Humuula	6685'	52.0°

x 1922 only

The relation may be seen more clearly by reference to the accompanying diagram (Fig. 5.)

Precipitation.

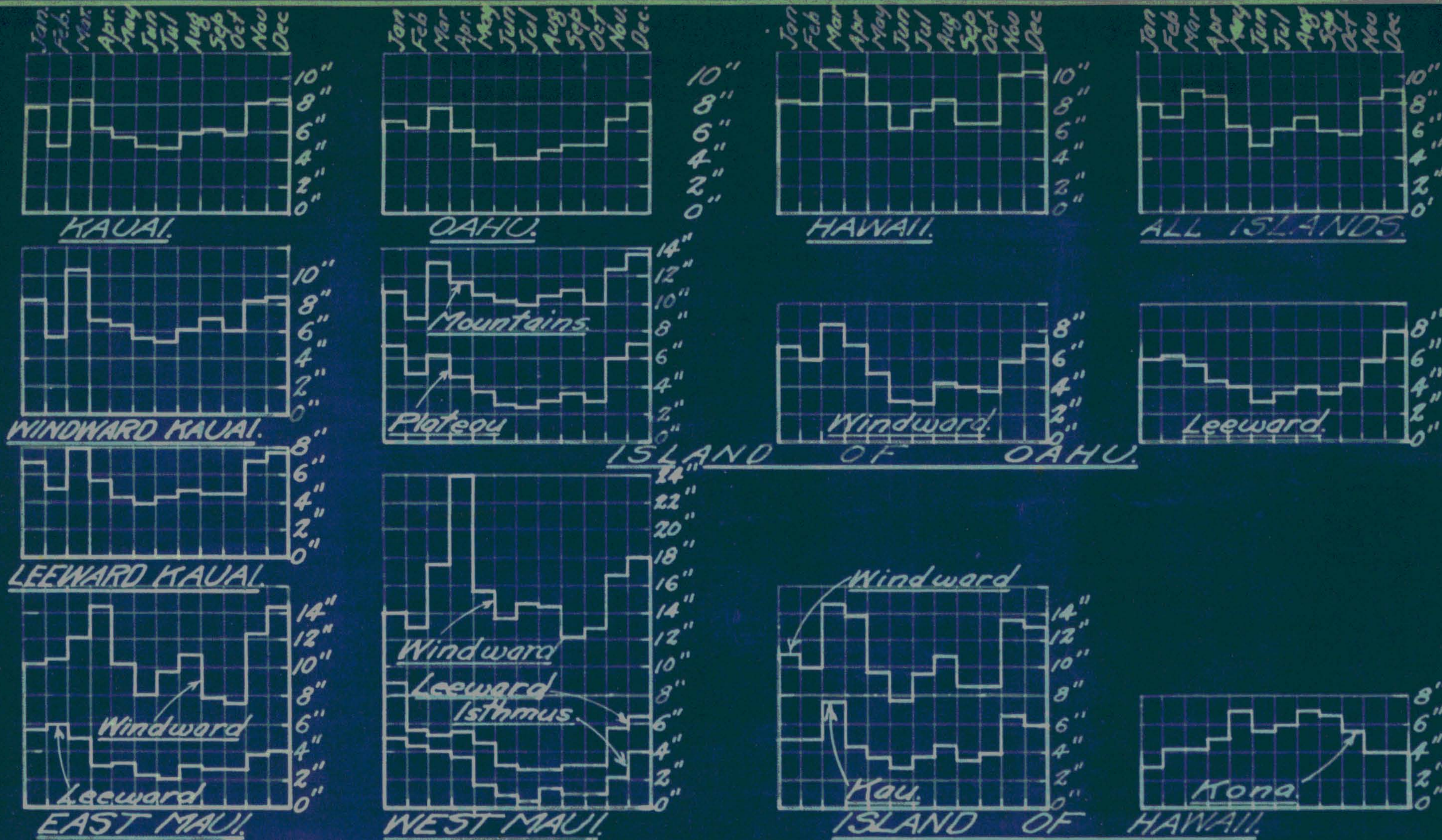
It well might be expected that, owing to the relatively small size of the several islands, their isolation, and the uniformity of the hydrosphere in the locality, the precipitation would be fairly uniform, as is the temperature. Such is not the case, however, On the contrary the variation in precipitation is one of the most striking natural phenenomena of the islands.

According to the records of the U. S. Weather Bureau the mean annual rainfall for all islands is 79.91 inches. The variation for official stations is from 2.46 inches to 562.00 inches per annum.

Taking the islands as a whole, there is a fair degree of uniformity in the comparative monthly distribution of precipitation as is indicated on the accompanying diagram.

A comparable uniformity is also disclosed by the records of the separate islands of Kauai, Oahu and Hawaii, on which the plantations under consideration are located, as is indicated on the accompanying diagrams (Fig. 6.)

Such comparative uniformity disappears, however, when we abandon the broad generalities and substitute for a study of specific data, whether they relate to individual plantations, or localities, or to considerable



DATA OF MEAN PRECIPITATION.

FROM RECORDS OF U.S. WEATHER BUREAU.

G.H.W.B. 32.

sections of the same island. That this is true, to a marked degree may be seen by reference to the accompanying diagrams of comparative monthly distribution of precipitation on the island of Oahu, Hawaii, Kauai and Maui.

Particular attention is invited to the heavier precipitation in the mountains, and on the windward sides of the several islands, and to the summer precipitation in the Kona region of the island of Hawaii. The influences of elevation, topography and wind movement are suggested by the diagrams. These will receive due consideration hereafter.

It will be of advantage to consider more specific data than have been presented in order that the problems of the plantations under consideration, and plantations having comparable conditions, may be understood better. In Table No. 4 is shown the mean monthly and annual precipitation for stations located on the plantations under consideration:

TABLE 4.

MONTH	KEALIA	KOLOA	KEKAHA	KAHUKU	EWA	OLAA	17-mi.
Jan.	4.00"	5.86"	3.40"	4.16"	2.95"	11.12"	14.97"
Feb.	3.96"	5.46"	3.23"	5.22"	4.10"	10.40"	14.07"
Mar.	6.81"	7.35"	3.91"	5.07"	2.85"	15.19"	17.95"
Apr.	2.50"	4.82"	1.16"	2.82"	1.11"	15.22"	20.76"
May	2.43"	4.87"	1.07"	2.01"	0.91"	10.35"	16.21"
Jun.	1.92"	4.31"	0.35"	1.60"	0.59"	9.18"	13.23"
Jul.	2.00"	4.49"	0.40"	1.80"	0.39"	11.87"	17.96"
Aug.	1.87"	4.92"	0.94"	2.32"	0.74"	13.17"	20.01"
Sep.	3.02"	4.75"	1.29"	2.27"	1.04"	11.64"	15.98"
Oct.	3.16"	5.14"	1.39"	2.51"	1.09"	10.81"	14.14"
Nov.	3.98"	6.47"	2.45"	3.90"	2.81"	17.84"	22.85"
Dec.	5.06"	6.02"	3.07"	4.11"	3.22"	16.15"	18.92"
Annual	40.81"	64.46"	22.66"	37.79"	21.80"	152.92"	206.95"

It will be observed that the annual rainfall at the 17-mile station on Olaa Plantation is nearly ten times as great as that on Ewa Plantation or Kekaha Plantation, while the mean maximum monthly precipitation at 17-mile is more than five times as great as that on Ewa.

Neglecting the stations on Olaa plantation for the moment, we find that the average mean monthly and annual precipitation for the other stations is as follows:

TABLE 5.

MONTH	INCHES
January	4.07"
February	4.39"
March	5.20"
April	2.48"
May	2.26"
June	1.75"
July	1.82"
August	2.18"
September	2.47"
October	2.66"
November	3.92"
December	4.30"
Annual	37.50"

From the standpoint of drainage it is as essential that consideration be given to the rate of precipitation as to the amount. A striking feature of Hawaiian climatological data is the high rate of precipitation both for very short periods and storms of a duration of one or more days. The maximum recorded amount of water falling in one day for the following stations is:- Kealia 8.70 inches, Koloa, 10.30 inches, Kekaha 10.93 inches, Kahuku 9.57 inches, Ewa 9.47 inches, Olaa 12.20 inches, and 17-mile 21.40 inches.

It is rather interesting to note that, with the exception of that at 17-mile which is at a high altitude, the records vary but little from the average figure of 10.20", notwithstanding the fact that the stations are located on three different islands, both on windward and leeward sides and at elevations ranging from 15' to 241'.

The total amount of water falling during the entire storms on the occasions of which the foregoing records were established is as follows: Kealia 9.55 inches, Koloa 13.81 inches, Kekaha 13.35 inches, Kahuku 11.82 inches, Ewa 10.89 inches, Olaa 17.27 inches and 17-mile 26.23 inches.

With the exception of the 17-mile station, all others are located at plantation headquarters and, therefore, at comparatively low elevations.

It will be of interest and, no doubt, of value to enquire into the relation between topography and rainfall. In the first place, as is indicated by the forgoing diagrams, the precipitation is higher generally on the windward side of the islands. The prevailing wind is from the northeast and the movement of moisture-laden clouds is blocked to a greater or less extent by the volcanic peaks which rear their heads so high above the sea. A considerable proportion of the moisture supply is precipitated on the windward slopes.

An exception to the general rule is introduced by the Kona storms, during which the movement is from the southwest and the leeward slopes receive the bulk of the precipitation at such periods. The diagramm referring to the Kona section of the island of Hawaii is a good illustration of this point. Without such Kona storms large areas now arable would be rendered arid to a high degree.

On several of the islands studies have been made which indicate that within certain limits, the amount of precipitation increases with altitude. The following table has been prepared from the records of the U. S. Weather Bureau.

TABLE 6.

OAHU RATIOS

STATION	ELEVATION	RELATIVE FACTOR
Honolulu Naval Station	6'	50
Honolulu Weather Bureau	99'	60
Kaliula Peak	1200'	220
Tantalus Peak	1360'	250
Tantalus Peak	1665'	410

HAWAII RATIOS

STATION	DISTANCE FROM OCEAN	ELEVATION	RELATIVE FACTOR
Olaa Mill	4. mi.	210'	100
Kurtistown	7 mi.	640'	115
17-mile	11 mi.	1530'	140
Glenwood	21 mi.	2300'	145
Volcano House	25 mi.	3984'	359

The zone of maximum precipitation appears to be different on the several islands, but in any event it is above the zone in which the plantations under consideration are included. It will be sufficient to bear in mind that in the plantation areas, generally, the amount of precipitation increases with the altitude.

In addition to the presence of the mountain barriers, and the relation of altitude to rainfall, many local influences, including land mass, as in the case of Hawaii and east Maui, shape and trend of the several islands, relative proximity to the sea, topography of the landscape and relation of wind movements, combine to produce complex climatological condition that respcting rainfall. Records obtained on one part of a plantation may have little application on another part and certainly records obtained on one plantation are of little avail in studying the problems even of an adjacent plantation. This was brought out forcibly by a comparison of data from Kahuku and Hauulu, during the week January 6 to 13, 1923, when 28.00" of rain fell at the latter place and only 3.88" at the former. On January 13, 9.00" fell at Hauula and only 2.20" at Kahuku. These stations are equally near the sea, both within a few feet of sea level, both on the windward side of Oahu and only six miles apart.

Run-off.

Considering the relatively high average precipitation and the intensity of storms, together with the high degrees of slope encountered in the uplands, a very high rate of run-off might well be expected. Heavy erosion, not only of the primary rock masses, but of the overlying soil would appear to be a natural consequence.

It has already been pointed out that erosion of the rock masses has not been highly developed, except in special instances. It is equally interesting to discover that soil erosion has not been intensive. This is due primarily to the fact that the rate of run-off is very much lower than would be the case generally under mainland conditions. There appear to be three reasons for this anomaly, first, that the soil is generally protected by a carpeting of vegetation; second, the soil itself has a most remarkable moisture holding capacity and high erosion resistance; and third, that the underlying rock masses, which generally lie at moderate depths, have a high percolation factor. The aa lava is usually thoroughly broken up and the pahoehoe lava is generally well suplied with contraction cracks and fissures, while the successive flows are separated by residual disintegrated material. The coral formations, too, are usually highly permeable, and, like the lava, often possess pukas into which considerable streams of water may be discharged without overcharging the subterranean passages.

Owing to the high permeability of the geologic structure and the relative proximity of the agricultural lands to the sea, the ground water table is generally very near sea level, and its plane is very nearly horizontal instead of approximating the surface configuration as is the case on the mainland, particularly where irrigation is practiced.

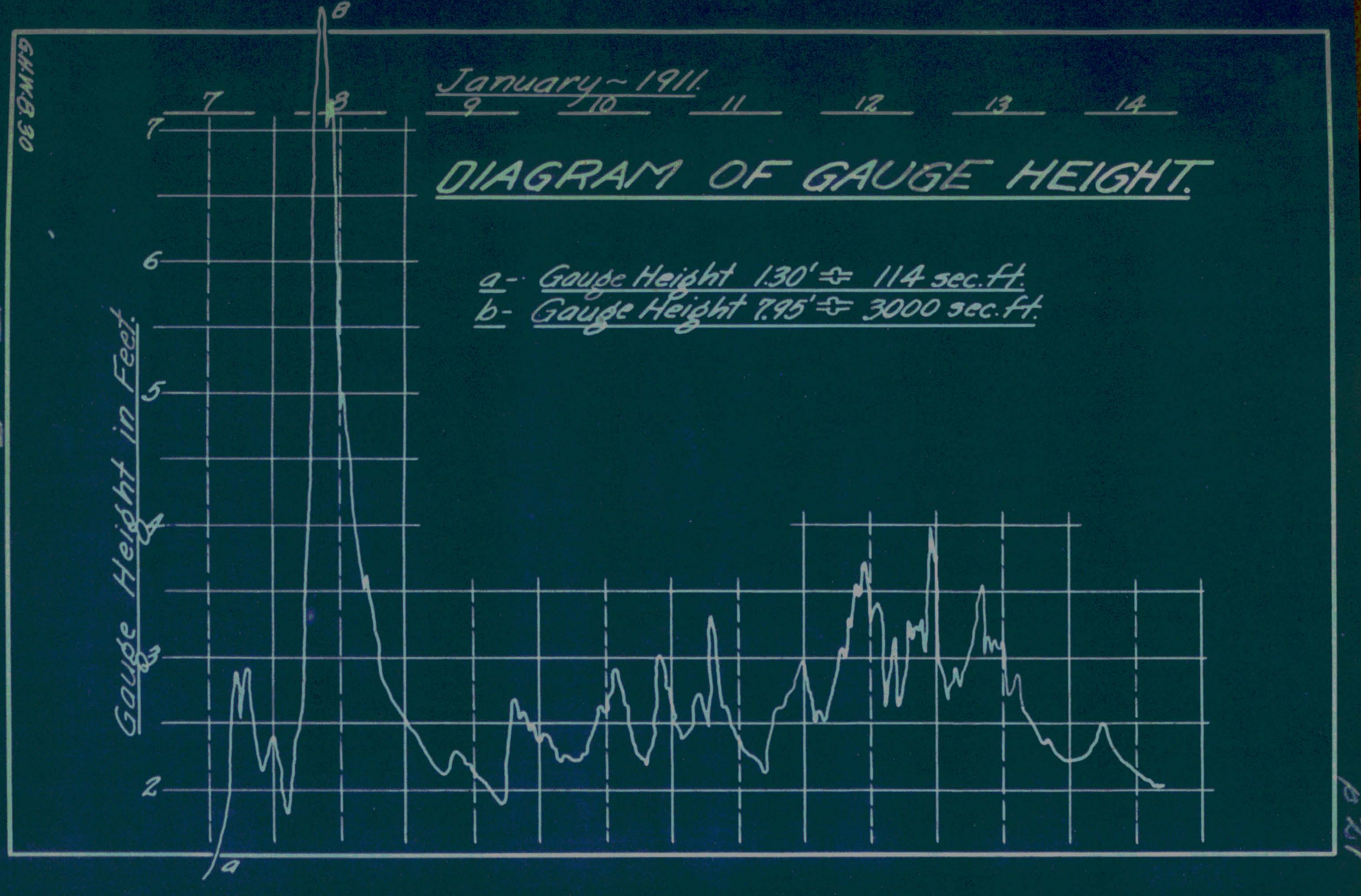
This condition, which has such an important bearing on the rate of run-off, is indicated by the fact that most of the pumping plants on the islands have their source of supply at or near sea level, indeed many plant pits have been sunk approximately to sea level.

A specific example in point is the well at Olaa Mill. This well is located about 4 miles from the sea and the subterranean flow is found at an elevation about 15 feet above sea level. This leaves about 210 feet of permeable structure at the particular point, to serve as a percolating medium. At Kurtistown and 17-mile, the elevations are respectively 640 and 1530 feet, as we have seen, and a correspondingly greater depth of permeable structure is provided.

The relation of the soils themselves to the matter of run-off will be discussed in detail hereafter when consideration is given to the subject of the soils.

Such run-off as occurs is flashy in the extreme. Innumerable cascades are produced on the steep mountain sides and the water courses became seething torrents. In areas like the Hamakua coast of Hawaii, hundreds of waterfalls are produced as the storm water plunges over the abrupt lava formations into the sea. A few hours later the channels may be comparatively dry. In illustration of this point, the accompanying diagram, (Fig. 7), taken from the records of the U. S. Geological Survey, is presented to indicate the erratic behavior of a certain stream. The hydrograph of an intermittent stream would be even more striking.

Fig. 2


January ~ 1911.
DIAGRAM OF GAUGE HEIGHT.
a- Gauge Height 1.30' = 114 sec.ft.
b- Gauge Height 7.95' = 3000 sec.ft.
Gauge Height in Feet.
7
8
9
10
11
12
13
14
2
3
4
5
6
7
a
8
GHWB 30

Evaporation.

In general the amount of evaporatinn from a water surface depends upon the relative temperatures of the water and the atmosphere, and upon the humidity and motinn of the latter. It is greatest when the atmosphere is driest, the water warmest and the wind movement greatest. It is least when the atmosphere is moist, the air not in motion and the water temperature low.

It would appear from the foregoing that the most favorable location for a high evaporation rate would be in a desert of low altitude and high temperature with pronounced wind movement. Conversely, it would appear that conditions in the Hawaiian Islands generally are not favorable to a high rate of evaporation. It may be well to examine data of the controlling factors.

In the first place as has been shown, the mean temperature is 71.5° which is high as compared with mainland values. Mean temperatures for summer months are not so high as the mainland averages, nor are maximum summer temperatures. On the other hand, the winter values are not so low as mainland averages.

The relatively high average precipitation in the island involves an average of 180 rainy days per year, with 200 days classified by the U. S. Weather Bureau as cloudy or partly cloudy. These phenomen have a bearing not only on air temperature and humidity but upon the temperature of the upper layer of soil, and consequently, upon the evaporation from the soil. As an example, it was found near 17-mile, during the course of these investigations, that the surface inch of soil had a temperature of 74.75° when the air temperature in the shade was only 72.5°. This was due to the fact that the sun temperature was 77.45°. The atmosphere was hazy at the time and it is likely and it is likely that a greater difference between soil and air temperature in the shade, would have been found had the atmosphere been clear. The direct effect of cloudiness upon rate of evaporation from soil is apparent.

The following table has been excerpted from the 1921 annual report of the U. S. Weather Bureau as an indication of the condition respecting humidity.

TABLE 7.

MEAN BI-HOURLY RELATIVE HUMIDITY AT HONOLULU IN PERCENTAGES

	(A.M.)						(P.M.)						
	2	4	6	8	10	12	2	4	6	8	10	12	Mean
Jan.	79	79	81	76	75	72	72	71	75	76	78	79	76.1
Feb.	80	80	80	74	64	65	63	64	70	73	77	80	72.5
Mar.	73	75	76	70	59	59	57	58	64	68	69	71	66.5
Apr.	72	74	74	65	58	58	56	54	62	68	70	72	65.3
May	77	79	80	66	63	62	61	62	66	70	74	76	69.8
Jun.	73	73	73	63	58	56	55	58	62	68	68	70	64.7
Jul.	73	73	73	68	60	58	56	58	64	68	70	72	66.2
Aug.	74	74	74	65	58	57	55	58	65	68	71	71	65.8
Sep.	70	70	70	65	57	55	56	59	65	68	68	69	64.5
Oct.	74	75	76	70	64	63	61	64	70	71	72	73	69.4
Nov.	74	75	74	71	62	63	62	64	69	71	72	72	79.0
Dec.	76	76	75	72	67	68	66	68	73	75	75	76	72.2
Mean	75	75	76	69	62	61	60	62	67	70	72	73	68.5

The foregoing data indicate a fairly uniform and comparatively high relative humidity, the effect of which is greatly to reduce evaporation, thus effecting to a great degree the tendency toward a high rate resulting from the relatively high mean annual temperature.

As for wind movement it has already been pointed out that there is a prevailing wind from the northeast, modified by kona movements at certain times and places. The data are rather meager but the following table, excerpted from the records of the U. S. Weather Brueau is suggestive;

TABLE 6.

AVERAGE HOURLY WIND VELOCITY

Month	HAWI MILL, HAWAII.	HONOKAA, HAWAII.	HONOLULU (U.S.W.B.)
Jan.	15.7	11.2	10.8
Feb.	9.8	8.2	6.9
Mar.	11.2	7.6	8.1
Apr.	14.3	10.9	10.5
May	8.3	7.8	6.1
Jun.	15.4	11.5	8.5
Jul.	16.8	10.9	99.0
Aug.	13.7	9.4	77.9
Sep.	13.4	10.0	9.3
Oct.	10.3	7.6	7.1
Nov.	11.4	7.1	8.8
Dec.	11.4	7.4	8.5
Year	12.6	9.1	8.5

These data indicate a rather high degree of wind movement which makes for a higher rate of evaporation.

From the compensating nature of the various natural phenomena having an influence on evaporation it may be concluded that the rate of evaporation in the islands, generally, is moderate. That this is true is indicated by the following data excerpted from the records of the U. S. Weather Bureau;

TABLE 9.

EVAPORATION AND WIND MOVEMENT AT EVAPORATION PAN SURFACE

	HOEAE (UPPER) OAHU		MAUNAWILI RANCH, OAHU.	
Month	Evap. Inches.	Wind, Miles.	Evap. Inches.	Wind, Miles.
Jan.	3.477	1661	2.344	1769
Feb.	4.630	1259	2.859	1159
Mar.	4.952	1118	6.647	1260
Apr.	6.197	1227	3.621	1667
May	6.515	961	4.049	963
Jun.	8.233	1241	4.420	1294
Jul.	8.245	1305	4.016	1499
Aug.	7.293	1252	4.260	1413
Sep.	6.782	1187	3,757	1611
Oct.	5.193	1114	3.098	1198
Nov.	4.021	1034	2.815	1328
Dec.	3.722	1195	2.925	1400
Year	69.261	14,554	41.709	16,561

The Hoaea station is on leeward Oahu, on a hill crest at altitude 705 feet, about 8 miles north of Pearl Harbor. The Maunawili station is on windward Oahu, at elevation 250 feet, about 4 miles from the sea, and situated between two hills.

The foregoing data have all related to evaporation from a water surface., The present investigations are concerned more with the rate of evaporation from soils. Evaporation from bare soil, given proper moisture conditions, may greatly exceed that from a water surface, while evaporation from a crop-shaded soil, or a surface covered with trash or leaves, may be but a small fraction of that from a free water surface . The amount of evaporation from bare soil is governed largely by the moisture content of the top layer of soil as may be seen from the following table excerpted from "Use of Water in Irrigation" by Samuel Fortier.

TABLE 10.

EVAPORATION FROM SOIL AND WATER

KIND OF SOIL	PERCENT OF FREE WATER	WEEKLY EVAPORATION IN INCHES FROM SOIL	FROM WATER
Sandy loam	Saturated	4.75"	1.88"
Sandy loam	17.5	1.33"	1.94"
Sandy loam	11.9	1.13"	1.94"
Sandy loam	8.9	0.88"	1.94"
Sandy loam	4.8	0.25"	1.94"

Studies in the vicinity of 17-mile station on Hawaii, on Ewa Plantation on Oahu and on Koloa Plantation on Kauai indicate a very rapid distribution of the excess soil moisture after percipitation. Moreover, in the case of cane lands, the soil is usually well shaded by the crop and carpeted with trash so that the tendency toward excessive evaporation following a heavy precipitation is offset. Finally, air and soil temperatures are naturally lower, and the intensity of the sunshine likely to be less, and the humidity likely to be near the maximum, immediately after a precipitation.

It seems reasonable to conclude, therefore, that the rate of evaporation, like the rate of run-off, is relatively less than that on the mainland generally and that a much larger proportion of the precipitated moisture is taken care of by deep percolation.

Soil Temperatures.

One of the most important factors in the agriculture of the Territory is soil temperature. In general, soil temperature is controlled by, and approximately equal to, the mean annual temperature of the overlying atmosphere. It is subjected to several modifications, however, chief among these being the moisture content of the soil. The various relations indicated and the importance of soil moisture control will be discussed hereafter, when the subject of soils is being considered.

IRRIGATION.

With an average annual precipitation for the Territory of 79.91" it would appear that agriculture might be carried on successfully by natural means. It has already been pointed out, however, that the Weather Bureau stations, from the records of which the foregoing average was compiled are situated both within and without the agricultural area and include stations of high altitude. Attention was directed to the average rainfall on the several plantations under consideration (not including Olaa Plantation which is not irrigated). This figure is 37.50" per annum and under mainland conditions would be regarded as sufficient for most crops.

It is not sufficient, however, under Hawaiian conditions and as a result, irrigation is practiced on a very large proportion of the cultivated area of the island.

Sugar cane is the dominant crop of the Territory and it is not only a year-round crop but is a profuse feeder. It contains from 60% to 70% moisture and requires from 100 to 300 pounds of water to produce 1 pound of cane. For an average crop this is equivalent to from 10000 to 20000 tons and represents from 7 to 14 acre feet per acre.

An early investigation made at the H.S.P.A. Experiment Station gave the results included in the following table. The necessity and advantage of irrigation are demonstrated forcibly.

TABLE 11

YIELD OF IRRIGATED AND UNIRRIGATED CANE.

RAINFALL	IRRIGATION	TOTAL	YIELD OF SUGAR PER ACRE
46.56"	48"	94.56"	24,755npounds
46.56"	0	46.56"	1,600 pounds
		Difference	23,155 pounds

We have seen that at Olaa Mill the mean annual precipitation is 152.92". Irrigation is not practiced and the returns are satisfactory in the vinicity. This rainfall represents nearly 13 feet in depth. Data compiled by W. P. Alexander, Agriculturalist of Ewa Plantation from a number of investigations show that the usual irrigation practice in the islands is to supply water at the rate of 1,000,000 gallons per day for each 75 acres. This is equivalent to 15.1 feet in depth in the course of a year. Added to the average rainfall on the irrigated plantations, it represents an average water supply of nearly 18.2 feet in depth per annum.

So much for the necessity of practicing irrigation based on the mean annual rainfall. Let us now examine into the distribution of the annual precipitation by months. The table of comparative data already presented is repeated below for convenience:

TABLE 12.

MONTH	PRECIPITATION
Jan.	4.07"
Feb.	4.39"
Mar.	5.20"
Apr.	2.48"
May	2.26"
Jun.	1.75"
Jul.	1.82"
Aug.	2.18"
Sep.	2.47"
Oct.	2.66"
Nov.	3.92"
Dec.	4.30"
Annual	37.50"

The average monthly precipitation is 3.12". The average is exceeded during the months of January, February, March, November and December. The actual precipitation falls below the average during April, May, June, July, August, September and October. Now while sugar cane is a year-round crop, its greatest growth, and, consequently, its greatest water requirement occurs during the very months of sub-average precipitation, and the maximum requirement is almost coincident with the minimum supply, maximum temperatures and maximum evaporations. Taking, for example, the average June precipitation, which is the minimum, the average daily application is a little less than 0.06" which is about one-fourth of the average evaporation from a free water surface and represents about 123,000 gallons per 75 acres as compared with the 1,203,000 gallons per 75 acres represented by the usual irrigation application plus the average precipitation.

p. 36

The following table, indicating cane growth at Ewa Plantation, as reported by Mr. Alexander, is suggestive of moisture requirements:

TABLE 13.

Month	Growth of Plant Cane
Aug.	16.9"
Sep.	15.2"
Oct.	14.1"
Nov.	13.1"
Dec.	11.7"
Jan.	10.3"
Feb.	6.9"
Mar.	8.5"
Apr.	9.0"
May.	14.4"
Jun.	17.3"
Jul.	17.1"
Aug.	16.9"
Sep.	15.2"
Oct.	14.1"
Nov.	13.1"
Dec.	8.8"
Jan.	6.6"
Feb.	4.9"
Mar.	4.4"
Apr.	4.1"

The necessity for irrigation, therefore, is apparent.

It is not within the provence of this report to analyze the process, methods and duty of irrigation practice, as such, nor to criticize the apparent low duty of water obtained, but it is necessary to examine into these features to some extent, owing to their relation to the problems of drainage.

Irrigation is practiced upon most of the sugar plantations, on rice and taro lands, and to a small extent on lands devoted to alfalfa, truck and other crops. Pineapple lands are rarely, if ever, irrigated, Rice and taro usually are grown on low, wet lands and, while the lands are actually submerged a considerable part of the time, small irrigation streams are used and such irrigation plays but small part in the general scheme of things.

Sugar cane, then, is the crop of chief concern in the present study and it is of interest to note that, in the Territory, this crop is not matured in a single season but requires from 15 to 18 months for full development. The total water requirement, then, is not directly comparable with that of annual crops, particularly those whose growing season comprises only a portion of a year. Intensive studies have not been made of the irrigation practices in the islands, but it has been reported that the total amount of irrigation water applied to sugar cane for the entire growing period, averages about 19.03 feet in depth. This is at the rate of 11.32 feet in depth for a year. To the mainland observer this appears to be a very low duty, but Mr. R. M. Allen, an irrigation expert, experienced in both mainland and island conditions, states in his brochure "Information for the Irrigator", "Whether this is a high or low duty we are at present unable to say". Therefore, it is not for the mainland observer to criticize, but realizing that, as Mr. Allen states, "We have more crop shortages from lack of moisture than from any other cause?" and recognizing the human trait, evidenced wherever irrigation is practiced, to go to the extreme, in the use of water it is only reasonable to assume that there may be improper practices and excessive uses, and it is evident that any correction in such practices and uses not only would modify the drainage problems, but would effect a saving in water, Hawaii's most valuable resource, next to the land itself, and in the cost of its application, which is important, and the loss of plant fertility through deep percolation, which is serious. The suggestion is ventured that a very intensive and comprehensive study of the irrigation practice of the islands should be undertaken.

Drainage is concerned more with the methods of application and the amount of water applied at single irrigations than with the gross duty of water.

Among the sources of the irrigation supply may be mentioned diversion from permanent and intermittent streams, storage, tunneling on windward mountain slopes and through divides, seepage, springs, and wells, both artesian and non-artesian. Very little storage has been attempted owing to the topography of the mountain formation. The largest reservoir in the islands, is that on Koloa Plantation, with a capacity of only a few ~~hundred~~ thousand acre-feet. Tunneling has proved successful on quite a considerable scale, particularly on Oahu and Maui, Diversion from streams is an important source of supply on a number of plantations. The most important source of supply, however, is that of wells penetrating the lava formations. Where conditions are particularly favorable the water flows directly from the well but in cases it is necessary to pump the water from the well, whether or not it be artesian, to the lands involved.

As a rule, the water is pumped from the formation, at, or a little above sea level, and some very interesting elaborate and expensive plants have been installed. Most of the early plants were set in great pits sunk nearly to sea level to avoit suction lift. The plants usually comprise Riedler horizontal, duplix, double action pumps, direct connected to Corliss, triple expansion, 4-cylinder steam engines, having single flywheels, and being supplied with steam from a battery of Babcock and Wilcox oil-burning, water tube boilers set up at the mouth of the pit, up to 90 feet above the bottom. A number of these plants have a capacity of from 8,000,000 to 12,000,000 gallons per day and water is pumped to various heights usually ranging from a few feet to more than 200 feet. In extreme cases, water is pumped to a height of about 600 feet.

The newer plants comprise horizontal, centrifugal pumps driven by electric motors. One plant on Kahuku Plantation has a capacity of 14,000,000 gallons per day. The price of power is based on a sliding scale and in larger quantities costs less than 2 cents per k.w.h. One plantation reports a pumping cost of 5½¢ per million gallons per foot. Another plantation, employing a 15" horizontal, single-stage, Centrifugal pump, belt connected to a 2-cylinder, semi-Diesel engine, reports a pumping cost of $1.00 per 1,000,000 gallons with a head of 15 feet.

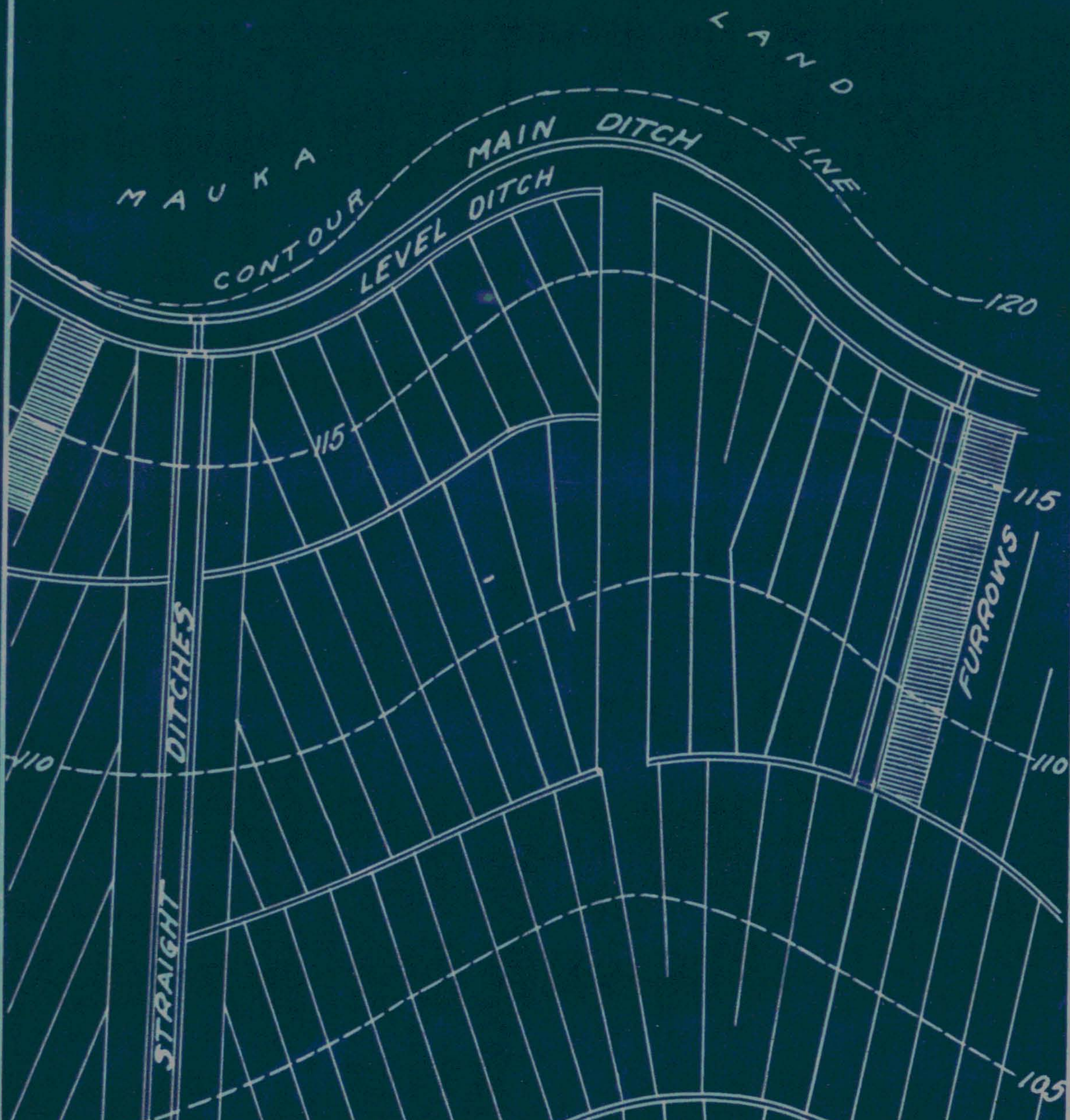
There are several layouts in vogue in the Territory for the irrigation of sugar cane but since they represent variations and modifications of the Hawaiian Furrow System, it will serve the purposes of this report to describe the basis system. The accompanying diagram (Fig. 8.) illustrates a conventional layout.

The elements of such a system are as follows:

1. Main ditch.
2. Straight Ditches
3. Level ditches
4. Watercourses
5. Furrows

The furrows are usually 30 to 35 feet in length and about 5 feet apart. They are laid out at right angles to the slope. Cane is planted in the furrows but the process of ridging up often culminates in an exchange of position of the furrows and the intervening ridges.

The length of the furrows fixes the spacing of the watercourses which run directly down the slope. The watercourses extend from level ditch to level ditch, the latter being from 200 to 300 feet apart, depending upon the topography, and being very nearly level. The straight ditches, in turn, run directly down the slope and are spaced to fit the topography, generally occupying ridges.



TYPICAL HAWAIIAN FURROW SYSTEM.

G.H.W.B. 25.

Fig. 8.

Water is diverted from the ditch into one or more straight ditches by means of headgates. Headgates may or may not be used in diverting water from the straight to the level ditches. They are rarely used in diverting the water from the level ditches to the watercourses, while diversions from the watercourses into the furrows is usually made by means of barriers of trash and earth. Water is run in each furrow, from one side of a watercourse, as a rule, but one of the modifications of the basic system is to run water in alternate furrows, trash being placed in the furrows not irrigated, in order to reduce evaporation and to keep down weeds. Another modification is to place barriers midway in the length of each of the furrows and irrigate half furrows both ways from the watercourses.

Several of the modifications of the basic system involve the cutting of ways between the ends of furrows and causing a stream of water to flow back and forth through two or more furrows.

Recently, a system called the "no-watercourse system" has been evolved. In this the furrows are run straight down the slopes from one level ditch to another. It is comparable to the orchard system in vogue on the mainland, and when provided with automatic control effects a great saving in labor.

Irrigation by flooding has proved so wasteful of water that it is resorted to only in times of critical labor shortage.

In all of the usual systems, a very complex network of irrigation channels is involved and this presents some rather unusual problems in drainage design.

Irrigation in the territory sometimes is carried on under very unusual conditions of slope as may be seen by reference to the accompanying figure.(Fig. 0). In the figure a watercourse and a number of furrows may be seen, the trash barriers indicating the positions of the latter.

Fig. 9.

Irrigation of Steep Slope.

35.

To offset the difficulties and disadvantages of irrigation under such conditions there is a relative freedom from drainage problems. Adjacent lower lying lands, having flatter slopes, however, are subject to injury by water seeping from the higher lands, even though the former possess comparatively good slopes and relatively good natural drainage.

DRAINAGE.

Drainage of irrigated land is largely concerned with the ready removal of waste irrigation water, whether it be moving over the surface of the ground or by slow percolation through the soil pores. Under any of the usual layouts in vogue in the Territory, there is little or no surface waste, although some water may collect in depressions, to the detriment of the growing crops and to the soil, in which event, provision should be made for the ready entry of such water into a drainage system.

It is the losses by seepage, then that must be investigated in a consideration of drainage design. Such losses may occur during conveyance or by deep percolation from the irrigated soil. Conveyance losses begin at the main ditch and extend throughout the whole network of reservoirs, delivery ditches, straight ditches, level ditches, watercourses and even the furrows, although the latter generally may be regarded as a part of the deep percolation directly from the irrigation of the soil.

Losses in the main and delivery ditches are often serious and are well recognized, particularly where the ditches cut into lava or coral formations or where leaky flumes exist. A considerable amount of attention has been paid to the repair of flumes and other structures and to the lining of the ditches, and important savings have been effected. Such losses, occurring in the higher portions of a plantation, and generally under favor-able conditions of slope, do not involve a drainage problem on the lands immediately adjacent, as a rule, but the water so lost contributes to the general underground body of water, tending to cause a rise of its upper surface, or under certain conditions of substrata, may produce a lateral seepage onto lower-lying lands. Lining of such ditches is the only possible method of preventing losses and where the value of water is great, this process should be feasible and economical.

Important losses from reservoirs take place but lining of such works is usually out of the question. Puddling, in some cases is feasible.

Serious losses occur also in the level ditches, but from the nature of their location and use they cannot be lined. Losses may be reduced by employing more care in the design and construction of the ditches and the use of more economical heads in irrigation.

Losses in watercourses are compensating, in some degree, since a large portion of the water so lost is likely to be retrieved by adjacent cane plants or to reach working soil at some lower portion of the field. Such losses may be held to a minimum if care is used in irrigation.

Water finally reaching the furrows is disposed of by surface runoff, evaporation from the soil, transpiration, and deep percolation. Under Hawaiian practice the first item is of little or no importance. The loss by evaporation from the soil is less than under mainland conditions since, as has been shown heretofore, the evaporation rate is lower and the closing in and self-stripping of the cane tend to shade and mulch the ground surface, further reducing this loss.

Transpiration involves the actual use of water by the plant and includes that which remains in the matured crop. It has been pointed out that the amount of water required to satisfy the transpiration needs of sugar cane is unusually high.

The minimum quantity of water required that should be applied, therefore, is equal to the amount evaporated and transpired. The optimum amount to be applied is somewhat in excess of the minimum amount, particularly in the event that the water supply is slightly saline. There is a well-defined gravitational movement of capillary water and it is perhaps axiomatic that unless the underground reservoir is "fed", during the process of irrigation, the plant roots will be deprived of their proper supply of moisture. The almost universal practice, however, is to apply an excess of water.

Investigations made at the Experiment Station of the Hawaiian Sugar Planters Association indicate that sugar cane roots rarely penetrate to the soil beyond four feet from the surface; that but a very small percentage of the root system is found in the fourth foot, while about a third of the system is found in the first foot and a major portion of the system is found in the second foot. Thus any water that penetrates below the four foot zone may be lost to use. The amount of water applied in one irrigation, therefore, is of concern both from the standpoint of irrigation and that of drainage. It has been shown for average conditions at the Waipio Substation that 3% of a two-inch, 47% of a six-inch and 65% of a nine-inch irrigation pass below a six-foot zone. Alexander concludes that, under Waipio conditions, it is impossible to store more than four and one half inches of water in the first six feet of soil, and that the figures would be less for a sandy or gravelly soil but greater for a finer-textured soil. Dr. Walter Maxwell, former director of the Experiment Station concluded that never more than three inches of water per week should be applied. Under field conditions, it appears customary to irrigate much less frequently, say, once in two or three weeks and to use up to eight inches or more in application.

It would appear from the foregoing that a drainage system might be called upon to take care of as much as three or four inches of water, under a condition of high water table, and since it would be disastrous to have the root zone surcharged with water for any considerable period of time, it would not be feasible to spread the removal over the entire period between irrigations, and were entire fields irrigated at once, as under mainland conditions, enormously capacious drainage systems would be required. Fortunately, however, but a few acres are irrigated per day in a given field so that the peak of drainage discharge would occur in one section of a given field at a time of little or no discharge in another section of the same field. It follows that main and sub-main drains need not be unusually large. Laterals, on the other hand, will need to have much greater capacity than under mainland conditions.

It would appear, from a comparison of rainfall data with the f figures indicating the amount of water applied in irrigation that no consideration need be given to precipitation in the design of an underdrainage system for an irrigated plantation. However, it must be borne in mind that the precipitation which is likely to be fairly uniform over the area in which a single drainage unit is involved, while the irrigation may progress at a rate, say, of only ten acres per day. Assuming an application of eight inches of water every sixteen days, progressing at the rate of ten acres per day over a field of 160 acres, it will be seen that so far as the main outlet drain is concerned, the average rate of application is one half inch per day. Maximum precipitations ranging from 17 to more than 20 times this amount have been recorded, while precipitations of several times this amount are not uncommon, even on plantations having a low annual rainfall.

In a number of instances, particularly where the irrigation water is pumped from sources near the sea and from strata near sea level, soluble salts are found in the water and some concern has been felt as to the ultimate result of using such water. In general, the conclusion has been reached that where the natural drainage is good and where the salinity is not in excess of 100 grains per gallon, no serious difficulties will develop. Lower duty of water has been recommended in the use of such water than in the case of normal water supplies and occasional copious applications of water as a leaching agent have been advocated.

The possibility of injury depends both upon the quantity of saline matter and upon the kind of salts present. The chlorides are regarded on the mainland as being much more injurious than the sulphates, while, under certain conditions, sodium carbonate is most injurious, owing to its action in deflocculating the soil structure.

Infiltration of sea water usually being responsible for the salinity of the irrigation supply in the Territory, it follows that the chief constituent of the salts found is sodium chloride and it safely may be said that extreme caution should be observed in the use of saline waters. Fortunately, sodium chloride is very easily removed by leaching so that with satisfactory drainage and copious applications of water, the chances are that moderately saline waters may be used continuously.

It must be borne in mind, however, that the vital factor is the quantity and quality of saline matter in the soil water in which the roots feed. Injury may result from the concentration, within the feeding zone, of water from a supply having a very moderate saline content. Again, injury may occur on soils showing a very low percentage of salt content, when the moisture content falls so low that a concentrated soil solution is produced. Finally, the quality of soil water may be unlike the quality of the water supply, owing to chemical reactions within the soil. This point is of special concern in the case of coral soils or soils in which coral is an important constituent. Reactions between the coral and fertilizer applied as sodium nitrate may result in the production of the dreaded sodium carbonate. Under such conditions, it may be well to consider the advisability of using ammonium sulphate as a source of nitrogen.

With respect to the point that the soil water may be unlike the source of supply in salinity, some special studies were made on one of the plantations. With a water supply having about 40 grains per gallon of soluble matter, the various soil water samples show the following results:

TABLE 14.

SAMPLE	DEPTH TO WATER	GRAINS PER GALLON	REMARKS
D-1	3' 0"	217.25	Poorly drained
D-3	2' 3½"	96.77	Fair drainage
D-5	4' 2½"	40.78	Well drained
D-6	1' 0"	41.08	Adjacent to ditch
D-7	1' 1"	131.53	Adjacent to ditch
D-9	10"	171.43	Poorly drained
D010	10"	146.54	Poorly drained
D-11	1' 0"	185.65	Poorly drained
D-12	9"	161.55	Poorly drained

In order that saline materials may not accumulate within the root zone, and on the surface of the ground, it is necessary that excess free water shall move downward through the soil freely and that the ground water table shall not rise within capillary reach of the ground surface. The most pervious soil is susceptible to injury if the ground water table is so near the ground surface that moisture may rise by capillary action and be evaporated from the surface, leaving its saline matter behind.

Where the natural drainage is insufficient or where the ground water table is too high part or all of the time, artificial drainage is necessary to protect the soil and the crops from injury due to saline accumulations. With good drainage, sweet water may be used on soils containing moderate amounts of saline mater, or slightly brackish water may be used on soils free, or comparatively free, from salts, but lacking good drainage, either combination eventually would be disastrous.

If soils are saline naturally, or if they have been rendered saline by irrigation with brackish water, they may be freed from the deleterious materials by leaching with copious quantities of water, providing good drainage is afforded. The question has been raised frequently as to whether leaching of soils irrigated with slightly saline waters should be done at intervals with large quantities of water, or whether an excessive amount of water should be used at every irrigation. The same question is involved in the case of saline lands to be redeemed by underdrainage and leaching. It is impossible to make a general statement as to what constitutes the best practice, but some observations and suggestions may be of value and will be offered in the section of this report dealing with the methods and operations involved in drainage reclamation.

SOILS.

The soils of the Hawaiian Islands have been derived almost entirely from basaltic lava, either as normal lava or as volcanic ash. The exception is presented by soils derived from coral formations, generally near the seashore and near tide level.

The soils are largely residual, and comprise relatively thin layers directly overlying the parent rock masses, of whose composition they naturally partake. It would be expected, at first thought, that with a common origin of nearly identical material and with transportation playing so unimportant a role, a soil of somewhat uniform type and class would prevail. This is not the case, however, since every known agency of disintegration, of which weathering is the most important, is at work. With respect to weathering, it may be pointed out that wide ranges of temperature and moisture conditions may obtain in closely restricted areas and that wind movements are of considerable importance. It follows that the soils of adjacent areas, even, may possess widely different characteristics and that the usual method of making soil surveys have been found inapplicable. Moreover, a given soil is in a state of change, the tendency ever being toward disintegration into finer particles. Soil and subsoil are not so unlike as under humid mainland conditions except in regions of excessive rainfall and plowing to depths up to 30 inches has been found to be feasible.

Chief interest attaches to the physical properties of the soils since these have to do with the difficulties of soil preparation and management, the lack of proper drainage and aeration and with the problems of irrigation and artificial drainage.

Prof. W. P. Kelley, former chemist of the Hawaii Agricultural Experiment Station, classified the soils [illegible] as clay, silt, sandy and humus soils. He states that the clay type predominates and that in some instances this type contains as high as 50% of clay. [illegible]

It appears, however, that the clay is not a true clay but is characterized by a high content of iron and aluminum hydrate and a double silicate of iron and alumina, instead of by the usual aluminum silicate. Elsewhere, such soils have been designated as laterites.

An important characteristic of such soil is that the clay is present in such a finely divided state as to be highly colloidal and when it is wet the iron and alumina are hydrated with the result that pronounced swelling of the soil mass follows. The soil pores are closed and the mass becomes a slick, impenetrable structure over which water slides with ease and without producing marked erosion. The writer has observed rivulets of water running down slopes as steep as one vertical to one horizontal without ill effects on the soil.

Insufficient aeration is a natural concomitant of the condition just mentioned and anaerobic conditions are likely to prevail. Upon subsequent drying out, the soil shrinks and cracks, often seriously injuring plant roots. The control of such changes in volume of the soil would be a distinct advantage and may be effected in some measure by proper drainage.

Many of the soils of the Territory are characterized by their large percentages of the finer materials, often being made up almost exclusively of fine sand, silt, fine silt and clay.

Soils which have been, or are now being devoted to the growing of rice are usually alluvial although their transporation has been very limited in most instances. They are largely of basaltic origin but, owing to their proximity to the sea, usually contain coral lime. They are often characterized by a high humus content. As a rule they are made up of comparable proportions of fine sand, silt and clay. The presence of coarse sand or gravel is unusual. In general they are classified as clay loams.

Another characteristic of many of the soils of the Territory is the high water holding capacity. This is reflected in the large irrigation applications and in the fact that heavy precipitations are absorbed with remarkably small run-off. Some special studies were made on one of the plantations which disclosed some very interesting and remarkable conditions respecting water-holding capacity, the counterpart of which have not come to the attention of the writer, heretofore, either in the field or in the literature dealing with soil moisture control. Field examinations were made following a two-day storm during which 3.63" of rain fell. A storm ditch, six feet deep, eroded to the lava, showed a slight trickle of water on top of the lava and the walls appeared saturated. Soil samples, taken at depths of 1, 2 and 3 feet from the surface, were analyzed and found to contain respectively 376.2%, 400.0% and 316.7% of water on the dry weight basis. No free water appeared at the 3-foot depth. During the next two days a precipitation of 5.79" was recorded and further studies were made. Separate holes were bored to depths of 1', 2', 3', 4', 5', 6', and soil samples were taken from each. Another hole was bored to a depth of 7½' where lava was encountered. Water stood at 6' 8" in this hole and a sample was taken from below water level with the hope of ascertaining the full water holding capacity of the soil under field conditions. In making the analyses, in addition to ascertaining the moisture content of the samples, the hygroscopic capacity of the samples were determined and a determination was made also of the amount of water required fully to saturate the samples. The results are given in the following table:

TABLE 15

DEPTHS OF SAMPLES	MOISTURE CONTENT	HYGROSCOPIC MOISTURE	WATER HOLDING CAPACITY
1'	223.10%	100.30%	283.60%
2'	344.05%	183.30%	415.50%
3'	333.65%	129.00%	369.00%
4'	311.52%	156.00%	386.60%
5'	233.33%	65.10%	287.90%
6'	279.51%	71.80%	304.00%
7'	230.03%	54.90%	271.50%

These figures are remarkable and especial interest attaches to the fact that, even with such copious precipitation, no free water was found within the root zone. In the discussion, hereafter, of the process of drainage reclamation, it will be shown that underdrainage of soils is not possible unless the free water rises above the plane of the drains. It is evident that there is an excessive amount of moisture in such soil, due to its slow downward movement and frequent replenishment, and that the solution of the difficulties involved must be based upon preventative measures. Artificial surface drainage, supplemented by proper soil management and perhaps, by artificial mulching, appears to afford the only relief. Recommendations for such treatment will be offered in the subsequent section dealing with methods and operations.

Under the conditions just mentioned, a dual problem of soil moisture control and soil temperature control is presented. Such control is concerned with the upper limit of permissible soil moisture content and with the lower limit of required temperature.

Fortunately the two aspects of the problem are related and a solution of the former aspect will, in considerable degree, satisfy the requirements of the latter.

The studies already made indicate that the mean annual rainfall at the site of the experiment is over 200 inches, which is of course excessive and that the area is subject to heavy storms, a precipitation as high as 21.4 inches in one day having been recorded in January 1922. The average number of days per year having a precipitation of 0.01 inch or over is 301, which indicates a high percentage of cloudiness. With respect to air temperatures, it has been found that the mean annual temperature is discouragingly low being 66.1° F (1922) as compared with 73.6° F at plantation headquarters and with 73.5° F as an average for twelve sugar plantations on Kauai, Oahu, Maui and Hawaii. The mean monthly temperatures in 1922 at the site of the experiment range from 62.5° F for February to 69° F for September. At plantation headquarters the mean monthly temperatures range from 70.0° F in January to 76° F in September and the range for the average of the above mentioned twelve plantations is from 69.8° F for January to 76.8° F for September.

All plants are subject to certain critical temperatures, both as respects to germination and growth. A sugar-producing plant is especially susceptible to the status of the supply of heat and sunshine., So far as the writer has been able to determine, no work has been done in the Territory relating to heat unit requirements and critical temperatures but it seems to be the consensus of opinion that the growth of sugar cane is largely suspended during amonth or so of minimum mean temperatures. By making a careful analysis of data from a large number of plantations, the writer concluded that development is unsatisfactory when the mean monthly temperature falls to 70° F or below. The following table gives the mean monthly annual temperatures for the site of the experiment (1922).

TABLE 16.

Month	Temperature
Jan.	63.5° F
Feb.	$62.5^{\circ\circ}$F
Mar.	64.0° F
Apr.	65.5° F
May	65.0° F
Jun.	67.5° F
Jul.	68.5° F
Aug.	68.5° F
Sep.	69.0° F
Oct.	68.0° F
Nov.	66.5° F
Dec.	64.5° F
Annual	66.1° F

It will be seen that the mean monthly temperature never reaches 70° F at the site of the experiment and one naturally wonders why cane grows at all in the locality. The following table of mean maximum monthly and annual temperatures at the site of the experiment may serve to shed some light upon this point.

TABLE 17.

Month	Temperature
Jan.	69° F
Feb.	68° F
Mar.	69° F
Apr.	71° F
May	70° F
Jun.	74° F
Jul.	75° F
Aug.	74° F
Sep.	75° F
Oct.	75° F
Nov.	72° F
Dec.	72° F
Annual	72° F

Maximum temperatures probably reach as high as 90° F and it might appear that such growth as is made is the result of heat units contributed during certain portions of the day during some seven or eight months of the year. Small wonder then, that cane growth and sugar content are relatively smaller than at plantation headquarters, where the temperature conditions obtaining are as indicated in the following table.

TABLE 18.

MONTH	MEAN	MAX.
Jan.	70.0° F	80.2° F
Feb.	70.5° F	80.8° F
Mar.	72.0° F	81.3° F
Apr.	72.5° F	80.8° F
May	72.5° F	81.6° F
Jun.	74.0° F	82.6° F
Jul.	75.5° F	83.2° F
Aug.	75.5° F	83.6° F
Sep.	76.0° F	84.0° F
Oct.	75.5° F	83.9° F
Nov.	74.0° F	82.3° F
Dec.	73.0° F	81.3° F
Annual	73.6° F	82.1° F

As for soil temperatures within the rootzone, it is a characteristic of tropical soils, that the temperature is somewhere near constant at a point near the mean annual air temperature. The investigations made showed an average soil temperature within the foot zone of 66° F as compared with a mean annual air temperature of 66.1°F for 1922.

With respect to air temperature, conditions must be accepted as Nature has provided them. It is not within our power to alter the percentage of cloudy days nor to raise the temperature of the air. With respect to the soil temperature, however, we may produce some modifications, artificially.

It was ascertained in the studies that there was a definite relation between soil moisture content and soil temperatures. This is indicated in the following table: the higher the moisture the lower the temperature -

TABLE 19.

% of Soil Moisture		Temperature
400.0%	(2nd foot)	64.4° F
376.2%	(1st foot)	65.3° F
316.7%	(3rd foot)	68.0° F

This is due to the fact that the quantity of heat required to raise the temperature of water one degree is about twice that needed to change the temperature of dry soil the same amount. Moreover, where the factor of evaporation enters in, about twenty times as much heat is required.

Artificial modification may be effected in two ways, one by moisture control and the other by conserving the available heat supply, first, by assisting the soil to absorb more heat, and, second, be eliminating loss of heat so far as possible.

The first control is correlated with the first factor of the dual problem, which has been mentioned, that of control of the upper limit of soil moisture. The second control involves a number of physical phenomena. It will be discussed in detail in the section dealing with methods and operations.

The finer-grained soils are very "heavy" and sticky, rendering plowing difficult. If plowing is done while the soil is too wet, there is danger of serious puddling. Puddling may result from other causes, as well. Some of the heavier soils resemble the adobe of the mainland.

Drainage may be depended upon to improve such soils, but their very character has a bearing both upon drainage construction and effectiveness. Trenching operations will be rendered more difficult by reason of the heavy, sticky nature of the soil, but caving of the banks of tranches will be less likely to occur because of its stability. The texture of such soils is such that drains are relatively less effective, thus requiring closer spacing, greater depth, or both, and in extreme cases, special location.

The color of the soil is generally of redish cast and may range from yellow, through various shades of red to deep brown, depending upon the state of hydration of the iron content. The normal color may be masked by the presence of humus, manganese, coral or black sand. The presence of manganese is of particular interest, not only because of its rather general distribution, but because of its effect in rendering iron unavailable. Titanium is also found in Hawaiian soils.

Don't copy here

Lime is found rather more abundantly than would be expected in a non-limestone area. The ratio of lime to magnesia is usually satisfactory but is sometimes reversed in soils derived from black sand.

Potash is below the average for agricultural soils but a higher proportion is available than usual. Its content is fairly constant.

Phosphoric acid, on the other hand, is abundant and its content variable, but its availability is low. It is not liable to excessive leaching, owing to its fixation, probably in combination with iron and alumina. This is of importance in the case of soils which will require leaching subsequent to the installation of underdrainage.

As a rule, the humus content is high, compared with mainland soils, and as a result the nitrogen content is satisfactory, but in many of the soils its availability is low, due to poor aeration. Drainage will be of value under such conditions, and, in general, will reduce the requirement of mineral fertilizer.

In case of rice lands, the aeration is particularly poor, but so long as rice is produced this is of small concern since nitric nitrogen is not suited to assimilation by rice and ammonification can take place in submerged soils. Indeed, dentrification can take place under saturated soil coditions, so commercial fertilizer is not applied as nitrate, and in management of rice soils, usual procedure is not followed, so that aeration is avoided, lest nitrification by stimulated under aerobic conditions, only to be followed by the formation of nitrites wh ich are injurious to rice. Drainage reclamation of such soils, therefore, must take account of their previous condition and treatment.

Sulphur, emitted during eruptions, has been the source of sulphates in some of the soils, and the presence of the latter must be taken into account in the selection of tile for the drainage of soils impregnated with soluble salts, since sulphates are injurious to concrete structures, particularly those having thin walls, like tile.

Iron is found very generally in Hawaiian soils. Its proportions are likely to be higher under conditions of heavy precipitation, owing to the leaching out of silica, lime, magnesia, soda and potash. In its ferrous state, iron is toxic to plants and under conditions of poor aeration oxidization may not be well advanced. Drainage will aid in such oxidization.

TIDAL VARIATIONS.

Certain lands in need of drainage are situated at insufficient elevation above sea level to permit of gravity drainage into the sea. Other lands, now devoted to the culture of rice, might be developed into cane lands, if provided with drainage, but most of such lands are very nearly at sea level.

There are two possible methods, in general, of providing drainage for such lands, first, by conducting the drainage water to sumps located near the sea and constructed below sea level, and pumping the water from the sumps into the sea, or second, by conducting the drainage water to capacious sea-level channels leading through levees to the sea and being provided with automatic tide gates which operate to permit the discharge of drainage water into the sea at low tide but prevent the movement of sea water back into the channels at high tide. A typical gate is shown in the accompanying figure. (Fig. 10).

The latter method is, of course, the more economical, and it will be well to enquire into its feasibility under conditions obtaining in the Territory. Following are tide data for Honolulu, for the year 1922, excerpted from reports in the office of the U. S. Weather Bureau:

Fig. 10.

Automatic Tide Gate.

TABLE 20.

TIDE DATA FOR HONOLULU - 1922.

MONTH	HIGH	LOW	MAX. DAILY VARIATION
Jan.	0.6' to 2.1'	-0.3' to 0.6'	2.3'
	0.5' to 1.4'	-0.5' to 0.2'	
Feb.	0.5' to 2.0'	-0.3' to 0.5'	2.3'
	0.5' to 1.4'	-0.4' to 0.1'	
Mar.	0.4' to 1.9'	-0.3' to 0.4'	2.1'
	0.6' to 1.6'	-0.3' to 0.2'	
Apr.	0.4' to 1.6'	-0.4' to 0.2'	2.0'
	0.7' to 1.8'	-0.3' to 0.3'	
May	0.4' to 1.2'	-0.5' to 0.0'	2.2'
	0.9' to 1.9'	-0.3' to 0.4'	
Jun.	0.5' to 1.3'	-0.4' to -0.1'	2.2'
	0.7' to 2.1'	-0.2' to 0.6'	
Jul.	0.6' to 1.7'	-0.3' to 0.1'	2.2'
	0.7' to 2.3'	-0.1' to 0.8'	
Aug.	0.8' to 1.9'	0.0' to 0.4'	2.1'
	0.8' to 2.3'	0.2' to 0.9'	
Sep.	1.0' to 2.0'	0.2' to 0.6'	1.9'
	1.0' to 2.2'	0.2' to 0.8'	
Oct.	1.1' to 2.2'	0.2' to 0.6'	1.9'
	0.7' to 1.9'	0.0' to 0.5'	
Nov.	1.2' to 2.2'	0.1' to 0.6'	2.1'
	0.5' to 1.5'	-0.3' to 0.3'	
Dec.	0.9' to 2.1'	-0.1' to 0.6'	2.2'
	0.5' to 1.1'	-0.5' to 0.2'	

The highest reaches occured in July, August, September, October and November. The high stages for the several periods involved are given in the following table:

TABLE 21

Jul.	High	Aug.	High	Sep.	High	Oct.	High	Nov.	High
20	1.9'	18	2.1'	16	2.1'	20	2.1'	18	2.1'
21	2.1'	19	2.2'	17	2.2'	21	2.2'	19	2.2'
22	2.2'	20	2.3'	18	2.2'	22	2.2'	20	2.1'
23	2.3'	21	2.3'	19	2.1'	23	2.1'		
24	2.3'	22	2.3'						
25	2.2'	23	2.2'						
26	2.1'	24	2.0'						
27	1.9'								

In the following table are given time and tide ratios for other Territorial positions:

TABLE 22

POSITION	TIME	HT. OF HIGH	RATIO OF RANGES	HIGH INTERVAL	MEAN RANGE	SPRING RANGE
Honolulu	0:00	0.0'	0.0	3hr.48min.	1.2'	1.8'
Kauai	+1:10	-0.2'	0.8	2hr.50min.	1.0'	1.6'
Hilo	-1:35	+0.4'	1.2	2hr.12min.	1.5'	2.5'

Tidal in Hawaii [illegible] not more than 2.5 feet

It will be observed that the ranges are very moderate. In order that satisfactory drainage might be afforded, it would be necessary that considerable storage capacity be provided in the channels. The system would be feasible only where each gate would serve a very small area.

It is reported that experience in the rice fields of South Carolina, where the tide range is from 2' to 2½', shows that difficulties in operation of the gates has made them unsatisfactory, while experience along the Atlantic coast generally seems to indicate that there should be a range of at least 4½ feet, particularly where subsidence of the soils follows drainage.

If tide gate control is attempted under island conditions, it will be advisable to divert storm water from outside and higher sources, through gravity storm ditches, to the sea, leaving the drainage canals and tide gates to care only for the water pertaining to the tracts themselves.

ECONOMIC ASPECTS.

It is reported that the Territory of Hawaii ranks third in the production of cane sugar for the world market, being surpassed only by Cuba and Java, and its contribution to the world supply is of no small consequence. Of greater importance, however, is the fact that sugar is the barometric crop of the Territory, and the status of industry generally throughout the islands is governed largely by the condition of this basic industry.

In its competition with Cuba and Java, the Territory is confronted with the fact that in Cuba the industry is founded upon an abundance of cheap land, in Java it is founded upon an abundance of cheap labor, while the Territory, possessing neither, must rely upon efficiency in operation and cooperation in activities.

It has been pointed out that the total land area of the principal islands of the group is about 6650 square miles. This is equivalent to about 4,250,000 acres. The area of improved agricultural land, however, is only a little more than 300,000 acres which is roughly 7% of the gross area. The area actually growing sugar cane is about three-fourths of the entire improved area, and for present purposes may be assumed as representing only 5% of the gross area. The importance of intensive cultivation of this area, its conservation, and its extension, are apparent.

The remaining 2% of the area classified as improved agricultural land is devoted to the growing of pineapples, rice, taro, truck, fruit, coffee, etc., or is fallow cane land. Until comparatively recently, rice was the crop second in importance and coffee production was of no small consideration. The production of rice has fallen off and the growing of pineapples has taken second place in the scheme of things. Rapid development of pineapple growing indicates that the Territory shortly will cease to be practically a one-crop country. No comment on the economic advantage is necessary.

While pineapple growing has supplanted rice growing as an important industry, it has not involved the substitution of one crop for another on the same land. Rice is grown principally on low, wet lands, generally near tide level, and often in areas of relatively high rainfall. It is an irrigated crop. Pineapples, on the other hand, are very susceptible to excessive moisture, require very little water and are generally grown on higher land, having a good slope and relatively good natural drainage. They are rarely irrigated.

Being susceptible to injury by excessive moisture, pineapples may be grown neither on low lands having a high water table nor on lands so high in elevation as to receive too much rainfall. In consequence, the early development of the pineapple industry took place in zones generally just above the upper limit of economical cane growing. Much of the land in such zones was regarded as almost worthless, so the new industry appeared to afford a fortunate combination.

The natural upper limit of such zones is fairly well fixed by topography or rainfall, however, so some subsequent extension of the pineapple area has been made at the expense of cane lands. Further extension of the pineapple area will involve some futher encroachment upon cane lands unless the upper limits of the zones are raised artificially. This can be done by providing artificial drainage for such areas, as has been indicated in the foregoing discussion of soils.

It appears desirable, if not economically necessary, to substitute cane for rice in much of the low-lying areas. As a rule, it is more economical to extend the cane areas down, rather than up the slope. This is particularly true where irrigation is practiced. Such extensions is possible, and is feasible wherever drainage may be afforded economically.

In the case of non-irrigated cane land, it is also feasible to extend the cane area up the slope, in the event the present limit has been fixed by excessive rainfall or comparatively low temperatures. Proper drainage would take care of the excessive precipitation and also would be of advantage in providing a measure of soil temperature control.

Manifestly, within the cane area, every acre of land that economically may be made to produce should receive due consideration. Where unproductiveness is due, either directly or indirectly, to excessive moisture conditions, artificial drainage offers the basis of redemption.

Furthermore, every acre of land devoted to the growing of sugar cane, or any other crop, for that matter, should be afforded every opportunity to produce at the highest economic rate. Artificial drainage is the basis for many improvements in soil conditions that make for high yield.

The system of land tenure in vogue is conducive to efficient operation. Much of the land upon which cane is grown is held in large blocks by estates, and is leased for long periods of time to the plantation companies. Most of the companies have their own sugar mills, so there is no conflict of interest between grower and manufacturer. Cooperation among the units was easier to obtain originally and is more effectively maintained than would be the case where the land owned and operated in small units, by individuals, while the manufacturing end represented a separate industry.

In connection with the problem of drainage, however, the leasing system presents a new aspect from the standpoint of economics. It is customary to base the economy of a proposed drainage reclamation project upon the relation of the annual cost of the reclamation to the increase in annual returns due solely to the drainage. Under the leasing system it will be necessary to give due consideration to the length of time the lease has yet to run and to the possibility of renewal under favorable terms. Proper drainage is regarded as a permanent improvement and, as such, increases the market value of lands, where such lands are subject to free exchange. Under Territorial conditions there is the possibility that the interests bearing the expense which enhances the producing power of the lands will be penalized by higher rates for renewal of leases, based upon such enhancement.

Drainage costs are likely to be relatively higher in the Territory. The various projects usually will be comparatively small and construction work will need to be done piecemeal, or through fields of growing cane. The general use of economical machinery does not appear to be feasible. The available labor is not experienced in trenching work and cannot be expected to operate efficiently. There are no materials in the islands suitable for the manufacture of hard-burned clay tile and any such tile used must be imported from the mainland. The use of concrete tile, as a substitute, may prove satisfactory.

Where pumping is necessary, particularly on irrigated plantations, continuous operation generally will prevail, although the amount of water will fluctuate between rather wide limits. Plants must be designed to care for maximum conditions. Such plants may be arranged to operate more or less automatically, where electric power is available, but a certain amount of attention is essential. It is submitted that the pumping of drainage water is economical as compared with the pumping of irrigation water for the same area since either the quantity of water or the head, or both, are less. Finally, drainage water often may be used for irrigation of lands, by pumping, and such conservation of water is commendable.

BENEFITS OF DRAINAGE

The first and most fundamental benefit that accrues as a result of the installation of an artificial underdrainage system is the removal of any excess water already occupying the pores of the soil in the drainage zone.

Removal of the free water naturally results in a lowering of the ground-water table wherever previously it had stood within less than drainage depth from the ground surface.

With a proper drainage system in operation, fluctuations in the position of the water table, within the root zone, are largely prevented. This result is of great importance, since plants are more susceptible to injury from a fluctuating water table, even at relatively greater depth, than from a permanently high water table.

Upon the removal of the excess water from the soil pores, air is drawn in, producing better aeration and establishing a condition under which the proper balance between air and moisture may be maintained.

Better oxidation and the neutralization of poisonous gases follow the introduction of a proper supply of air. Of particular importance in the Territory is the fact that where aeration is poor, the chemical state of the iron salts is unfavorable, and that the aeration produced by drainage corrects the difficulty.

The exchange of water for air tends to warm the soil, owing to the difference in specific heat of the two substances.

The length of growing season is increased as a result of a rise in soil temperature. In the case of cane, germination is expedited and the period of relative dormancy is shortened. Growth is more rapid throughout, and earlier harvesting is made possible.

Cultural operations are possible earlier in the spring and sooner after a storm or period of heavy precipitation or irrigation.

One of the most beneficial results of proper underdrainage, in a humid region, is that excess moisture, falling as precipitation, is taken care of with less injury to the soil or to the crop.

Excess water overflowing land, whether due to storm or to waste from irrigation, is absorbed more readily by a well drained soil.

In the case of irrigated soils, percolating water from the irrigation of the tract itself finds a ready means of escape. Likewise, water seeping from canals or the irrigation of higher lands may be intercepted by the underdrainage system, and the water prevented from doing damage to the lower lands.

If any harmful salts are held in solution in the ground water, they will go out with the drainage water, and if such salts have accumulated on the surface of the ground, or have crystallized out in the drier portions of the soil, their removal may be effected easily by subsequent leaching with water.

The subsequent accumulation of the deleterious materials is prevented by proper underdrainage and, in consequence, there is less danger in the use of slightly saline water in irrigation, while water of higher concentration may be used where suitable underdrainage has been provided.

A lowering of the ground water table is equivalent to increasing the available depth of soil, and numerous advantages are thus afforded. In the first place, the physical condition of the soil is improved as a result of better aeration, flucculation and fertilization. The rate of movement as a result of capillary moisture is increased as a result of better physical conditions. This is of great importance in the production of so profuse a feeder as sugar cane.

The available moisture content is increased, rather than decreased, by drainage. Most plants depend almost entirely on capillary moisture for their sustenance, the free water being practically unavailable. As a rule plant roots do not enter the zone of free water, and if a rise of the ground water takes place, roots will be injured. The root zone, is limited by the position of a high ground water table. Capillary moisture in the soil exists as a film surrounding the individual soil particles. Where the ground water table is high, the number of film-encased soil particles particles is limited. Lowering the ground water table results in deepening the zone of soil in which capillary moisture is segregated from free water, hence in an increase in the number of film-encased particles, hence in the available moisture content. A deeper, more complex rooting system is made possible, so that a thriftier plant is produced.

With shallow rooting and a limited moisture supply, the effect on plants, of a period of drouth, is often serious. With proper underdrainage, the deepter, more complex root system, and the larger available moisture supply make it possible for plants better to withstand such periods of drouth.

The same reasoning applies with respect to the available food supply as does to the available moisture supply. Furthermore the actual nitrate content is increased by drainage, due to the increased activity, both in zone and intensity, of aerobic bacteria and the decreased activity of anaerobic bacteria.

As a natural result of the improved conditions generally, crop production is increased. The quality of the crops produced is improved, also. In the case of sugar cane this may be expressed as an improvement in the quality ratio.

The tolerance of various crops for improper moisture, physical and chemical conditions, is not the same, and one important benefit of drainage is that crops of a higher class may be grown. Rotation of crops also becomes possible, and this benefit is frequently of importance.

As a consequence of all the foregoing benefits, financial returns are increased, and this result is, of course, the great desideratum.

There are many more or less indirect benefits flowing from the drainage of agricultural lands, among which the following may be mentioned:

Field operations, particularly with teams, machinery and equipment, are rendered easier and cheaper.

Highways are improved affording more economical transportation.

Foundations, fences, pole lines and structures are made more stable and lasting.

Wells, cellars and pits are improved.

Ponds and sloughs are dried up, with improvement in health conditions.

A better control and more economical use of irrigation water is made possible, owing to the larger soil reservoir afforded. Less water is required to irrigate drained than undrained soils, so that a further saving is effected. Moreover, the water developed by drainage may be used in irrigation so that, with a given water supply, additional land may be developed and additional crops may be produced.

Finally, in the case of irrigated lands, an educational function is served, in that excessive application of water is exposed and better practice is likely to follow.

PROCESS OF DRAINAGE RECLAMATION.

In general drainage may be divided into two classes, surface drainage and under-drainage. In the former, as is implied by the name, water moves over the surface of the ground, either generally or in more or less well-defined channels, while in the latter the water moves through the soil and subsoil and deeper lying structures, either in more or less well-defined channels or by slow percolation through the interstices of the media. In either case, gravity is the actuating force, and friction of the surfaces, channels or interstices is the opposing resistance. The movement of water is ever from a higher to a lower point, and drainage is good or insufficient just as the channels or interstices are of ample or inadequate capacity and as the ratio of gravitational force to frictional resistance is large or small.

Artificial drainage is subject to the general classification and the same factors enter into consideration. It should be kept firmly in mind that, by artificial drainage operations, we merely improve upon a natural status, to the end that the movement of water may be expedited over or through the soil or its underlying structures.

In artificial surface drainage, it is the aim to gather surface waters into more or less restricted channels and to expedite its movement away from the area involved, in order that only an optimim amount of water may enter the soil generally.

In artificial underdrainage, it is the aim to remove excess water from the soil pores, within the root zone, to lower a high water table, and to prevent fluctuations of the water table within the root zone and to expedite the removal, from the root zone, of any excess water that may reach the soil by downward percolation from precipitation upon, or irrigation of, the surface of the area itself, or by lateral percolation of seepage water from higher lands, reservoirs, canals or ditches.

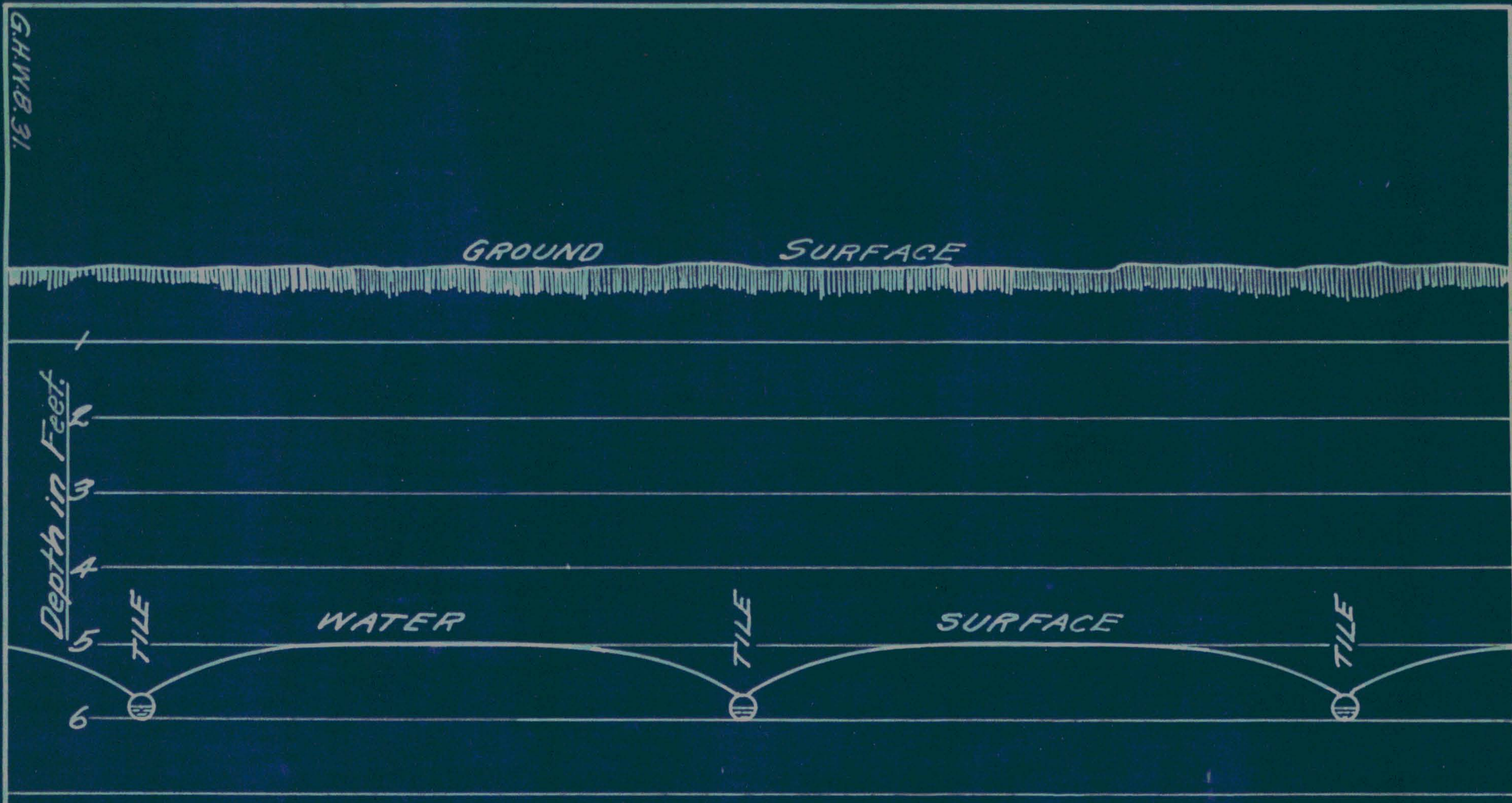
In order for artificial surface drainage to be effective, it is necessary only that all portions of the area shall have sufficient slope twoard some proximate channel to permit of the ready removal of water from the surface; sufficient channel capacity for the ready transportation of the accumulated water into a larger channel, serving a number of such proximate channels, and thence through a series of laterals, sub-main and main channels to a suitable ultimate outlet.

In order for artificial underdrainage to be effective, it is necessary that a sub-soil reservoir, within drainage depth from the ground surface, shall exist, either permanently or temperarily, and that the ground water table, whether permanent or temporary, primary or perched, shall be above the plane of the drains.

If the water table is high at the time drains are installed, a flow will be developed as the work progresses, the water table being lowered nearly to the depth of the water level in the drains adjacent to the drains, but curving upward sharply at a little distance from them, then less and less sharply at greater distances, until along a line about midway between drains, the ground water table is in closest proximity to the ground surface. The accompanying diagram, (Fig. 11.), presents a suggestive cross-section of a tile drained field.

The shape of the curves will depend upon the slope of the ground, the hydraulic qualities of the soil, the efficiency of the drains, and the elapse of time. If there is no additional supply, eventually the drains will cease to flow and the curves will become practically a straight line, due to natural drainage.

With the drains operating, any subsequent addition of free water to the soil above the ground water surface, however, will result in a tendency for the ground water table to rise. This is impossible



SUGGESTIVE CROSS-SECTION OF A TILE-DRAINED FIELD.

Fig. 11

immediately at the drains, granting that they are not overcharged, so that the rise between drains increases the hydraulic gradient toward the drains and expedites the movement of water into the drains, thus lowering the elevation of the crests in the water table, reducing the hydraulic gradient and tending toward the establishment of a stable condition.

In case the water table is below the drainage depth when the drains are installed, no flow will be developed. A subsequent addition of free water to the soil will cause a rise in the water table and as soon as this table rises sufficiently above the plane of the drains to overcome the friction of entry, water will percolate into the drains and they will begin to operate. If the supply is copious, the ground water table will take some such shape as indicated in the diagram to which reference has been made, the height to which the crests will rise depending upon the supply and the operation of the drains. If the supply is excessive, the drains will become overcharged and the ground water surface will rise above the drains at all points. So long as the drains are operative, however, the ground water table will be depressed in their vicinity. It is clear, therefore, that a controlling factor is the necessary depth to the ground water table at the crests.

The process involved in the removal of deleterious soluble substances is a reversal of that by which they are accumulated. Such substances are constituents of the parent rock masses, or of sea water, or are the products of natural reactions. They occur in the soil as a result of the processes of its formation and transportation, or as the result of application in solution through seepage from higher cources, through irrigation, or through translocation from underlying bodies of saline waters.

The phenomenon of their concentration on the ground surface and within the root zone is based upon the combined influences of capillary movement and evaporation. Soil water will rise above the free water plane, by capillary movement, to a height of from a few inches to a number of feet, depending upon the character and structure of the soil. The soil water contains the deleterious substances in solution. When the depth to the free water plane is less than the capillary rise for a given soil, capillary water, laden with soluble matter, rises to the surface of the ground, from which it is evaporated, leaving the soluble matter, behind, resulting in a concentration of the soil solution in the upper few feet of soil and in an accumulation of the substances on the ground surface.

To effect their removal, it is necessary, first, to lower the free water plane below the capillary reach and, second, to set up a downward movement of the concentrated solution, to the end that dilution may take place and that the salt-laden water may be removed through the drains. The matter accumulated on the ground surface is readily soluble and may be leached out by copious applications of water either by precipitation or by the irrigation process.

METHODS AND OPERATIONS

KINDS OF DRAINAGE

As has been suggested already, artificial drainage in the Territory is concerned both with irrigated lands and those whose moisture is supplied by natural precipitation directly. In some instances surface drainage only will be required; in other cases underdrainage alone will be involved, while on some of the plantations, both surface drainage and underdrainage must be afforded. In the present section, it will not be necessary to treat those two general kinds of drainage separately, since many of the considerations involved apply to both, but some comments will be made, here and there, in the discussion. In the separate appendices, which accompany this general report, more detailed suggestions and recommendations will be presented as required by the special problems of the several plantations under consideration.

TYPES OF DRAINS.

There are two general types of drains - the open ditch and the covered drain. Since this discussion deals with the problems of individual plantations and since the several drainage units are relatively small, no consideration will be given to the large open canals used for outlets in community or drainage district systems.

The open ditch, as its name implies, is merely a waterway cut into the soil so that it will receive the drainage from adjacent land. If intended to serve as a surface drain, it need have depth and capacity sufficient only to prevent overflow when fully charged, its purpose being to afford a ready means of escape for water flowing over the surface directly into it, or for water collected by other surface drains and discharging into it. If intended to serve as an underdrain, however, it must be afforded sufficient depth and capacity, so that when fully charged, the water surface in the drain will be at such a depth below the ground surface, that the subsurface water may continue to percolate into the drain without its plane being raised dangerously near the ground surface between drains. The open drain is used almost exclusively for surface drainage and may be used for underdrainage.

The covered drain consists essentially of an underground conduit for the collection and transportation of subsurface water. It is used almost exclusively for underdrainage, but by use of proper inlets, may be adapted for use in surface drainage. It is superior to the open ditch for underdrainage. The reason for using the latter is largely one of economy, although, where available grades are very flat, or where the required capacity is large, the open ditch possesses some advantages.

The open ditch itself takes up considerable space, and the material removed in its construction usually is of such quality that it is not wise to spread it over the adjoining land, at least for some years, so additional space is lost. Moreover, it is not safe to irrigate land close to such a channel, as there is danger of water breaking into the ditch, with consequent injury to it and to the land. Even a very small ditch may require that a strip of land several rods in width shall be rendered useless for agricultural purposes, so that an effective drainage system may reduce, materially, the available acreage of a tract. To keep an open ditch open, the sides must be made sloping, usually not steeper than one vertical to one horizontal, and to prevent the growth of vegetation and the accumulation of silt and debris in the channel from obstructing the flow, the bottom width should not be less than, say, 4 feet, ordinarily, so it becomes necessary to excavate much more material than in trenching for covered drains. Under island conditions, it is likely that side slopes may often be steeper and that narrower minimum bottom widths may be permissible, but, on the other hand, the loss of land area is of relatively much greater consequence.

Open ditches are unsightly and provide harborage for obnoxious weeds and breeding places for injurious and disagreeable insects.. Their presence is a constant source of danger to farm animals. They cut up the fields into inconvenient and irregular shapes and require the installation of bridges and flumes in order to facilitate communication between the various parts of a field and for the conveyance of irrigation water and waste water from tract to tract. Finally, in spite of careful design, construction and operation, open ditches are sure to require a great deal of maintenance and repair, and the expense for these often amounts, in the long run, to more than the extra cost of covered drains.

Covered drains, on the other hand, are not subject to these objections. They take up no valuable space, and if properly installed require little or no maintenance. The only way in which difficulty can occur, in connection with vegetation, is the possibility of roots entering and choking the drains, and this cannot occur if lines are kept away from water-loving trees and if injurious plants are not permitted to grow over or near drain lines. The root zone of cane is well above usual drainage depth and it does not seem likely that cane roots will endeavor to penetrate tile lines. The usual cultural operations should serve to prevent injury but some difficulty may be experienced with honohono.

Open drains have an advantage over covered drains where grades are flatter than, say, five feet per mile. They also possess an advantage where the quantity of water to be taken care of is relatively large, since, with an increase of tile diameter, available depth is sacrificed, while the capacity of an open ditch may be increased by widening its cross-section, without increasing the depth of flow.

The most suitable material for use in a covered drain is clay tile. It should be hard-burned but not brittle. The two-foot length is the most satisfactory. The tile should be straight and truly cylindrical in shape. Thw walls should be smooth and be free from serious cracks and blisters. The ends should be free from rough edges and irregularities. The tile should be uniform in size and thickness for any given diameter. The walls should have fairly uniform thickness at both ends and at various points of the circumference. They should be very impervious and have a low porosity. Their strngth should be sufficient to withstand any weight of backfill that may be placed upon them. The materials from which they are made should be free from foreign ingredients, particularly cinders and free lime.

Pole drains, brush drains, mole drains, rock drains and cobble drains are almost useless for the drainage of irrigated soils, or for soils subjected to excess ive rainfall,and never should be installed. Lumber box drains have been used to some extent on the mainland as a substitued for clay tile, but their use is a doubtful enonomy and is not approved. Cement tile is a vert satisfactory substitute for clay tile where no injurious materials are present in the soil water. Their use cannot be recommended, however, where sulphates are present in the soil. In any case, they should be made of the best materials, fabricated according to the highest standards with respect to mixture and consistency, be molded by approved machinery, and be treated with the utmost care in the process of curing.

DEPTH OF DRAINS.

An artificial surface drainage system for cane lands will usually comprise the following elements: main drain, sub-mains, laterals, sub-laterals and furrows. The furrows should have sufficient depth to cut through the upper layer of soil and bed in material less likely to erode. The sub-laterals should have sufficient depth to afford a free discharge into them of the water from the furrows at all times. The same factor must be considered with respect to the discharge of water from sub-laterals into laterals, the laterals into sub-mains and sub-mains into the main. Furthermore, in the case of the larger ditches, consideration must be had for economical design. The most economical cross-section is that in which the depth is equal to twice the hydraulic radius, or in the case of a rectangular channel, to one-half the width. Manifestly, it will not be feasible always to afford the most economical cross-section and in some cases ditches will have much greater relative width. There is no particular advantage in affording excessive depth, while unit costs of excavation increase with depth, and in some places lava rock or coral might be encountered. The chief end to be attained is to guard against overflow of the channels at time of maximum discharge.

With respect to the required depth for underdrains, two aspects must be considered. First, the ground water must not be permitted to rise into the root zone for any considerable period of time, and, second, where the soil or the irrigation supply contains injurious salts, the ground water table must not stand within capillary reach of the ground surface. These salts may become concentrated on the ground surface, even though the depth to the water table be several feet. The soil moisture rises several feet above the free water table in the soil, and this moisture is charged with harmful salts wherever the ground water contains such ingredients. The harmfulness depends in a large measure upon the concentration of the soil solution, so a given amount of salt may become harmful if transpiration or evaporation removes a portion of the water and leaves the salts. It is important, therefore, to lower the water table deep enough that the plant roots will not feed in salty solutions.

The height to which water will rise by capillary attraction varies with the kind of soil, being greater in the case of fine-grained, compact soils than in loose, coarse-grained soils. The height of rise in clay often is twice as great as that in sandy loam. If the sand be very fine, however, the height of rise may be nearly as great as in clay. Experience throughout the entire arid West has led to the conclusion that drains rarely should be placed at depths less than 6 feet.

Island conditions are more favorable than mainland conditions with respect to the latter aspect. Shading by the cane plants, mulching as a consequence of the stripping of the cane and lower rate of evaporation work together to minimize the tendency for accumulation of salts, while the application of the copious quantities of water required in irrigation, and the occasional heavy precipitations, tend to produce and keep up a downward movement of the soil water. In consequence, somewhat shallower depths may be permissible than under mainland conditions.

Where the situation is not complicated by the presence of harmful salts, the required depth of drains is fixed largely by the depth of the root zone. It has been shown in a previous section of this report that the roots of sugar cane rarely penetrate below four feet, that but a very small proportion of the root system is found in the fourth foot, and that a major portion of the root system is located in the second foot, under normal conditions. It would appear desirable, therefore, to keep the crests of the water table between drains at least 4 feet from the ground surface. The drains would need to be somewhat deeper, as pointed out in the discussion of the process of drainage reclamation. The extra depth required would depend upon the character of the soil and the spacing of the drains.

In the case of a homogeneous subsoil, the effectiveness of a drain increases with the depth. The subsoil is almost never homogeneous, however, and any change in formation has an important bearing on the required depth of drains. This is true whether the change is from a compact to a loose formation or vice versa. It is especially true if a stratum of either more or less pervious material is found within, say, 10 feet of the ground surface. For instance, assume that the tract under consideration is injured by seepage from higher land; that the first 2 feet of soil consists of loam, the next 4 feet of clay, and that under the clay is a layer of sand a foot thick, followed by more clay. The depth to the top of the sand stratum is, therefore, 6 feet, and if a tile drain be installed 6 feet deep, it will lie on top of the sand layer. As may be expected, the damaging water seeping from the higher land, moves through this sand layer, therefore, the drain will fail to intercept it and the drain will be a failure. Moreover, the sand makes a very unstable foundation for a drain, and the tile will be likely to get out of alighment, off grade, and even be up-ended and filled with sand. Even if none of these things happen, there is great danger of sand and silt making their way into the tile and obstructing it. It is quite evident that the tile should be land on the clay underlying the pervious stratum or, perhaps, be imbedded slightly into it. In that case there would be no danger of the tile getting out of position and the drain would be very effective. Thus the affording of an additional foot in depth often makes the difference between success and failure. It is necessary to know the existing underground conditions in each case before the proper depth can be decided upon.

Much the same situation would arise if the soil were a sand with a hard impervious layer at, say, 7 feet. Water reaching the tract by seepage from higher land would be likely to move along the impervious layer, and if a drain were laid at a depth of 6 feet, the water would continue to pass under it and the tile would be likely to become displaced and obstructed. Manifestly, the correct practice would be to lay the tile on, or slightly in, the hard, stable stratum.

In the case of a subsoil that changes from a relatively pervious to a less pervious structure at, say, 6 feet, it would not be wise to install drains at considerably greater depth, since they would then be laid in material yielding very little water, and the effectiveness of the system would be little greater than if the drains were installed only 6 or 7 feet deep, and the expense of the extra cutting would be ineffective at the greater depth. If the subsoil were a joint clay, or one that shrinks upon being relieved of its excess water, however, it might drain as readily as sand.

Most plants are adaptable to more or less stabilized unfavorable conditions, and it was observed by the writer that very satisfactory sugar cane was being grown in various portions of the Territory where the ground water table was found at depths of less than 4 feet. A lesson may be drawn therefrom, in connection with drainage. One of the benefits of drainage is that fluctuations of the ground water table are greatly modified, and it follows that the idea of drainage reclamation should not be abandoned merely because a drainage depth of more than 4 feet is not available in certain instances, even though such depth may be advocated generally. It appears that increased tonnage and improved quality ratio may warrant drainage at depths somewhat less than 4 feet, even though full value of drainage is not realized. The writer would not undertake, without actual field investigations of operating drains, to fix a minimum limit for depth but it was his observation that satisfactory cane was not being produced where the water table was within 2 feet of the surface.

Trenching to a depth in excess of 8 feet is rarely necessary or economical and does not appear to be required under island conditions. The question of keeping the ground water table up to the optimum depth is involved also. It is the opinion of the writer that depths of from 4 to 6 feet will be found effective and satisfactory.

SPACING AND LOCATION OF DRAINS.

The question as to how far apart drains should be spaced does not admit of a definite answer. The problem of design is more one of location of drains than of spacing, and the two factors must be taken together, the latter usually depending largely on the former.

For surface drainage, the furrows may be located betweenadjacent or alternate cane rows. They will likely run more or less with the greatest slope. Sub-laterals will naturally occupy the minor depressions, or in a vert flat area will intersect the furrows at frequent intervals. Laterals should be located in the more pronounced depressions from which the minor depressions radiate, and thus throughout the system to the main drainwhich must lead to an ultimate outlet. Such a system is designated a "relief system".

In case of underdrainage, the damaging water may have have several sources of supply and, likely as not, it will be moving laterally through the soil instead of percolating downward from surface application. The chief sources of supply, aside from direct precipitation on the surface of the tract itself, are downward percolation of the excess of the water used in the irrigation of the tract itself; surface run-off from higher land, supplied as precipitation, irrigation, or seepage brought to the surface; lateral underground seepage from the irrigation of higher lands, and losses from ditches, canals and reservoirs: and, in some instanced, direct natural seepage from mauka lands.

Ordinary drainage methods would serve for the removal of the moisture applied directly to the tract itself, from whatever source, but this constitutes only part of the problem. In many instances it is necessary to intercept lateral seepage from higher lands before the damaging water reaches the tract in question. Often a combined system is required.

In the interception of lateral seepage the question of location is of higher importance, while the matter of spacing is of little, or no, consequence. One properly placed line of drain will be more likely to reclaim an injured area than a dozen lines placed at random, however closely they may be spaced. Under mainland conditions, it is not unusual to find that a single drain will reclaim a 40-acre tract, when it can be located so that it will intercept the damaging water along the line of its appearance at seepage. For instance, considera tract of land injured by seepage from higher land. The seepage appears usually a long a belt at the change of slope from a steep to a lighter grade. If the sub-soil be examined, it probably will be found that there is a more pervious stratum, say sand, at a depth of several feet. This pervious stratum acts like a pipe line, leading from the source of supply and pouring the damaging water into the lower land, since the flatter slope is insufficient to carry the water away as rapidly as it reaches the tract. Now, if a drain be installed just below the line of the change of slope, at, or near, the upper edge of the injured area, and is at sufficient depth to cut through the sand layer, the flow of water will be intercepted and the water will be carried away by the drain without doing damage to the land. It is not essential,. however, that a more pervious stratum be present, since the reduction in slope is sufficient to cause injury, and an intercepting drain would operate to prevent such injury. Under island conditions, a counterpert of the foregoing situation is presented in the case of land located at the foot of a pali.

The conditions must be studied thoroughly and to a sufficient depth to make sure that there is no pervious stratum underlying the drain, through which the water may seep to the lower land. In case such a stratum exists at a depth, say, of 10 feet or more, it may not be feasible to reach it with a drain, but a drain of ordinary depth may be installed and relief wells may be bored in the bottom of the trench, to the stratum, thus providing passageways through which the water may rise and enter the drain.

An intercepting drain may be used to prevent water from seeping into close-textured soil. Such a drain is much more effective than a relief drain, installed in the compact soil for the purpose of draining out accumulated water.

After an intercepting drain is installed and seepage from outside sources is cut off, the natural drainage of the tract often is sufficient to take care of the water applied to the tract itself. This is not likely to be true under island conditions and it will be found necessary to install drains to remove the excess water. The question of spacing may come in here, especially if the tract be rather flat and if the surface topography be rather uniform.

At this point it may be well to point out that depth of drain also has a bearing on spacing, and that the element of time is involved in a consideration of the effectiveness of a drain. In the discussion of the effect of a drain on the topography of the ground water table, it was shown that the crests rise somewhat above the level of the water in the drains. The amount of this rise is greater for clay than for sand. It is greater for a wider spacing of drains, other conditions being equal, than for a closer spacing. Deepening of drains would result in a lowering of the crests. Such deepening, therefore, is equivalent to bringing drains closer together. The amount of the rise is greatest immediately after a contribution of water. It decreases with the time and, if the period between contributions is long enough, normal conditions will be restored, however compact the soil and however great the spacing. The success of a drain is measured by the rapidity with which normal conditions are restored rather than by the fact that ultimately they are restored. The degree of resistance of the crop to temporary unfavorable moisture conditions, therefore, is a factor in the question of spacing of drains. Data are not available on this point and until dependable information is obtained, it will be wise to design conservatively with respect to spacing, and generously with respect to capacity. It is the judgment of the writer that, under average soil conditions in the Territory, and with depths ranging from 4 to 6 feet, spacing of from 200 to 300 feet should prove satisfactory. In the sandy soils, greater spacing may be permissible, while in the case of the most compace soils, much closer spacing may be necessary.

If the tract in question be cut up by swales and depressions, the installation of a regularly spaced system is not advisable. Generally, in such cases, the drains should be located in the swales. The latter arrangement has some exceptions in cases where the soil underlying the swales is less pervious than that underlying the higher ground. Often it is necessary to have the drain lines run at the edges of the swales. It has been found necessary in some instances to locate the drains on the higher ground.

The installation of drains below the wet area, with the idea of draining out the water, should be attempted only when the subsoil is a coarse gravel, and not then, even, if the land above the wet area has a greater slope.

As a rule drains in the irrigated section of the mainland run across the natural slope rather than down the slope. The reason for this is that with the drains running down the slope, the damaging water would be moving in the same direction that the drains run and, consequently, very little water would reach the drains. The remainder continuing to reach the lower land and doing damage. The only land drained would be that in the immediate vicinity of the drain lines.

In the location of drains on irrigated plantations, due consideration must be given to the layout of the irrigation system. Intercepting drains will be required just down the slope from main and delivery ditches in some cases and just down the slpe from field reservoirs in many cases. In general, intercepting drains will run nearly parallel with the level ditches. They should not run too close to such ditches, however, and should not cross them if it is possible to avoid it. As a rule they should be located just above the level ditches and they should not be located just below them. Owing to the low grade available, it will be necessary to make intercepting drains short and conduct the developed water directly down the slpe to sub-main or main drains. Conducting drains likely will be required between adjacent straight ditches in most instances so that the intercepting drains will not cross straight ditches. If the topography is rolling, the best location for such conducting drains is down the slight depressions

Main drains should occupy the lowest portion of the given area, and sub-mains should occupy the diverging depressions.

In the location of underdrains, it will be necessary also to have due regard for the location of storm ditches. In some instances storm ditches may serve very well as main and sub-main drains, but as a rule, it will be well to keep the storm ditch system and the underdrainage system separate. Even if a storm ditch has sufficient depth to provide a suitable outlet for underdrainage, normally, it is apt to be overcharged just at the time underdrainage should be most effective.

A further point in connection with the relation of the location of underdrains to the layout of the irrigation system is that, wherever feasible, provision should be made for reuse of the developed water for irrigation purposes. Water intercepted well up the slope, often may be brought to the surface by gravity, in conduits or channels having less grade than the natural slope. Where this plan is not possible the water may be collected at some favorable point or points and be pumped through moderate head to irrigate nearby lands. In either case a regular outlet should be afforded for use when the water is not required in irrigation.

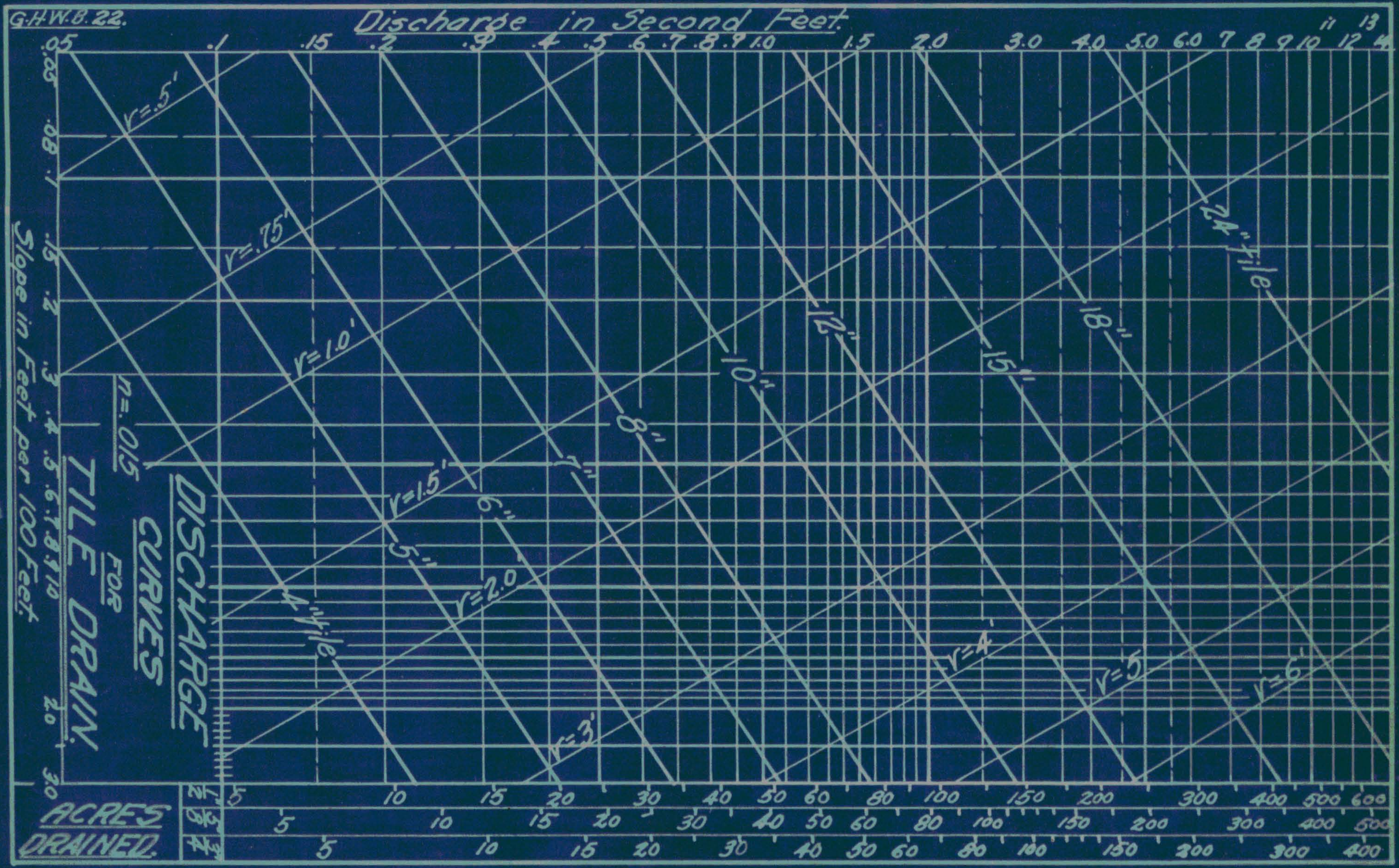
SIZES OF DRAINS.

In the following discussion, it will be assumed that open ditches only will be used in the case of surface drainage and that both open drains and covered tile drains will be used in underdrainage.

The size of open drain required in any case depends upon the amount of water to be carried, the slpe of the canal, the condition of the channel, and the shape of the cross-section of the water flowing in the channel. All of these factors influence the velocity of flow, which should be low enough to prevent erosion and yet high enough to prevent silting and the growth of vegetation in the channel. The desired velocity controls, to a large extent, the values that should be given to the foregoing factors, Average soils will stand a velocity of three feet per second, and a velocity of 2 feet per second will prevent the growth of most vegetation and the deposition of silt. The slopes required to give these velocities vary from one-half foot per mile in large canals to a number of feet per mile in the case of small ditches. In general, if the ratio of the depth of flow to the cross-section of flow be small, greater slope will be necessary or permissible. Under island conditions there is generally less danger of erosion and for this reason higher velocities may be permitted. Tables governing the various factors of design are available to all engineers and it will be unnecessary to include such tables in this report.

The size of tile required for underdrainage depends upon the amount of water to be carried, upon the slope of the drain and upon its hydraulic qualities. The slope can be decided upon when surveys are made and the fall to outlets is determined. The hydraulic qualities depend both upon the characteristics of the separate pieces of tile and upon the characteristics of the drain line as a unit. In other words, a properly laid line of tile will carry more water for a given size of tile than one laid on uneven grade, having poor alignment and improper joints. The accompanying diagram of tile capacity data is based on the assumption that proper methods of design and construction be used. (Fig. 12).

It is with respect to the amount of water to be carried, that the chief difficulty arises in the design of drainage systems, from the standpoint of size of channel or conduit. This is particularly true in the case of underdrainage owing to the fact that the damaging water moves underground and its occurrence, movement and behavior are somewhat secret and occult. No general statement can be made as to the


G.H.W.B. 22.
Discharge in Second Feet.
.05 .1 .15 .2 .3 .4 .5 .6 .7 .8 .9 1.0 1.5 2.0 3.0 4.0 5.0 6.0 7 8 9 10 11 12 13 14
Slope in Feet per 100 Feet.
n=.015
DISCHARGE CURVES FOR TILE DRAIN.
r=.5'
r=.75'
r=1.0'
r=1.5'
r=2.0'
r=3'
r=4
r=5
r=6
4" tile
5"
6"
7"
8"
10"
12"
15"
18"
24" tile
ACRES DRAINED.
5 10 15 20 30 40 50 60 80 100 150 200 300 400 500 600
5 10 15 20 30 40 50 60 80 100 150 200 300 400 500
5 10 15 20 30 40 50 60 80 100 150 200 300 400

amount of water which will reach a drain, either surface or covered, and there is no general drainage coefficient which may be applied to the area served, extent of drainage system, or other factor. The best that can be done is to examine into the various factors having a bearing on the problem. Each project, and in some cases, each drainage unit must be worked outindependently.

Attention will be given to the problem of design for surface drainage, first. Assuming a spacing of furrows of about 4 feet, a square acre would have about 51 furrows. If these furrows are made about 8 inches deep, so as to cut into the more stable material, given a width of 1 foot at the assumed water surface and a depth of flow of 3 inches and fair side slopes, it would require but a moderate fall to give a velocity of flow of one-half foot per second and a discharge of one-tenth cubic foot per second for each furrow, which is equivalent to 5 cubic feet per second from an acre of ground, or a total of 5 acre inches per hour. Manifestly such a net work of furrows would more that take care of the heaviest rainfall that ever would occur and that, for all practical purposes, greater spacing of furrows, greater lenght of run and less slope safely may be provided.

But, as has been pointed out already, not all of the water precipitated runs off the ground surface. A moderate amount is re-evaporated shortly after being precipitated, the crop requires its quota, the soil absorbs unusually large amounts of water and natural drainage ever is operative. The percentage of the total precipitation which is represented by surface run-off depends upon the amount of the precipitation and its rate offall, the size and shape of the area involved, the topography of the area, the nature of itscovering, characteristics of the soil and its moisture condition just previous to the precipitation, the nature and condition of the crop, and numerous other factors.

In general, it will be necessary to make rather extended investigations of actual run-off from the area under consideration and to couple the data so obtained with rainfall records in order that sufficient capacity may be afforded to care for the heavier storms. It likely will not be feasible to provide for maximum conditions.

In some cases, it will be necessary to go further and provide for an augmented surface run-off. It has been pointed out already that, in areas having an excessive rainfall, the soils may contain an excess of moisture, due to its relatively slow percolation andfrequent replenishment, even though no free water reservoir is created within the root zone, so that underdrainage would be ineffective.

In such a case, it will be necessary to reduce the proportion of the precipitation entering the soil and thereby increase the rate of surface run-off. This may be done by expediting the removal of precipitated water from the surface of the soil by sloping the intervening ground toward the furrows, and in some cases, perhaps, by providing an artificial covering to aid in shedding the excess water. In the design for capacity under such conditions, it will be necessary to ascertain the water requirement to provide for evaporation, transpiration, soil-moisture replenishment and deep percolation, and to provide surface drainage capacity for the difference between this amount and the total precipitation.

With respect to underdrainage, it will be advisable to consider the required capacity of drains for irrigated lands separately from that of drains for humid lands.

Under humid mainland conditions, it is customary to provide underdrainage capacity sufficient to effect the removal of from one-fourth inch to three-fourths inch of water in 24 hours. In some cases, systems have been designed with capacities as low as one-eight inch and as high as one inch. In general, it appears that the higher figures willbe required under island conditions, and it is likely that even more generous design will be required in certain cases. Manifestly, it would be out of the question to provide for the maximum rainfall reported for one of the plantation stations in the section dealing with precipitation, since this would require a tile capacity for at least 5 inches in 24 hours. Fortunately, this rainfall was recorded at a station for which surface drainage rather than under-drainage will be required. Maximum rainfalls for other stations would require a drainage capacity for the removal of from 2 to 3 inches, but such rainfalls are so uncommon that it will not be necessary to provide for them.

It will be advisable in each instance to install observation wells in the affected area and record the fluctuations of the ground water table due to measured rainfalls. The difference between the optimum moisture content and the water holding capacity of the soil should then be determined, and with these data in hand, a drainage capacity sufficient to restore normal conditions within a reasonable length of time should be afforded.

Inthe case of underdrainage for irrigated soils, as has been pointed out already, it will be necessary to consider both the application of water in irrigation and that due to natural precipitation. The first will have to do largely with the design of laterals and sub-laterals, while the latter will have to do with the design of main and sub-main drains.

Much of the reasoning presented in the case of underdrains for humid lands will apply to the problem of design of mains and sub-mains for the irrigated lands.

In the design of laterals and sub-laterals for the drainage of irrigated lands, it will be necessary to have due regard for the amount and rate of application of irrigation water to the tract in question. If seepage from outside sources is not of great consequence, this factor will be of chief importance, since the drains will run dry or nearly dry between irrigations. If seepage from outside sources is of considerable importance, it is clear that the drains will not run dry and that a smaller margin is afforded between minimum and maximum flows.

Under mainland conditions, it is customary to provide a drainage capacity of from one-fifth to one-third of the irrigation application. Sometimes less capacity is required and in some cases a greater capacity has been found necessary. Under the conditions of present practice in the islands, it is likely that provisions should be made for a capacity of, say, one-third of the application for average soils, with somewhat less for the more compact soils to make a careful study of the ground water fluctuations and moisture requirements in each instance and design accordingly.

Manifestly, intercepting drains located at the foot of palis or at changes in slopes from a steep to a lighter grade, may receive water from areas of considerable extent. Their design must be more generous for this reason, and is measured by the amount of water that can pass through the soil and into the drain, under the given conditions of water table slope and soil permeability.

It may be said, in general, that the very small sizes of tile sometimes employed on the mainland should not be used in the Territory.

Ordinarily tile less than 6 inches in inside diameter should not be used. If 5-inch tile is used, it should be employed for short unimportant lines only, or at the upper ends of sub-laterals.

On the other hand, it is not likely that tile larger than 18 inches in diameter should be used owing to the danger of breakage of the larger sizes and to the fact that the required depth of drain increases with the diameter. The following table is suggestive of the relative carrying capacities of the several sizes of drain tile, when laid on the same grade:

TABLE 23.

One	Will Carry the Discharge of
6-inch tile	Two 5-inch tiles
8-inch tile	Two 6-inch tiles
10-inch tile	One 8-inch, one 6-inch and one-5-inch tile.
12-inch tile	One 10-inch, one 80inch and one 5-inch tile, or three 8-inch, or seven 6-inch, or twelve 5-inch tiles.
15-inch tile	One 12-inch, one 10-inch and one 8-inch tile, or three 10-inch, or five 8-inch, or twelve 6-inch, or twenty 5-inch tiles.
18-inch tile	One 15-inch, one 12-inch,and one 8-inch tile, or three 12-inch, or five 10-inch, or nine 8-inch, or twenty-one 6-inch, or thirty-three 5-inch tiles

The larger sizes of tile are more economical in cost than the smaller as may be seen by reference to the accompanying diagram (Fig. 13)

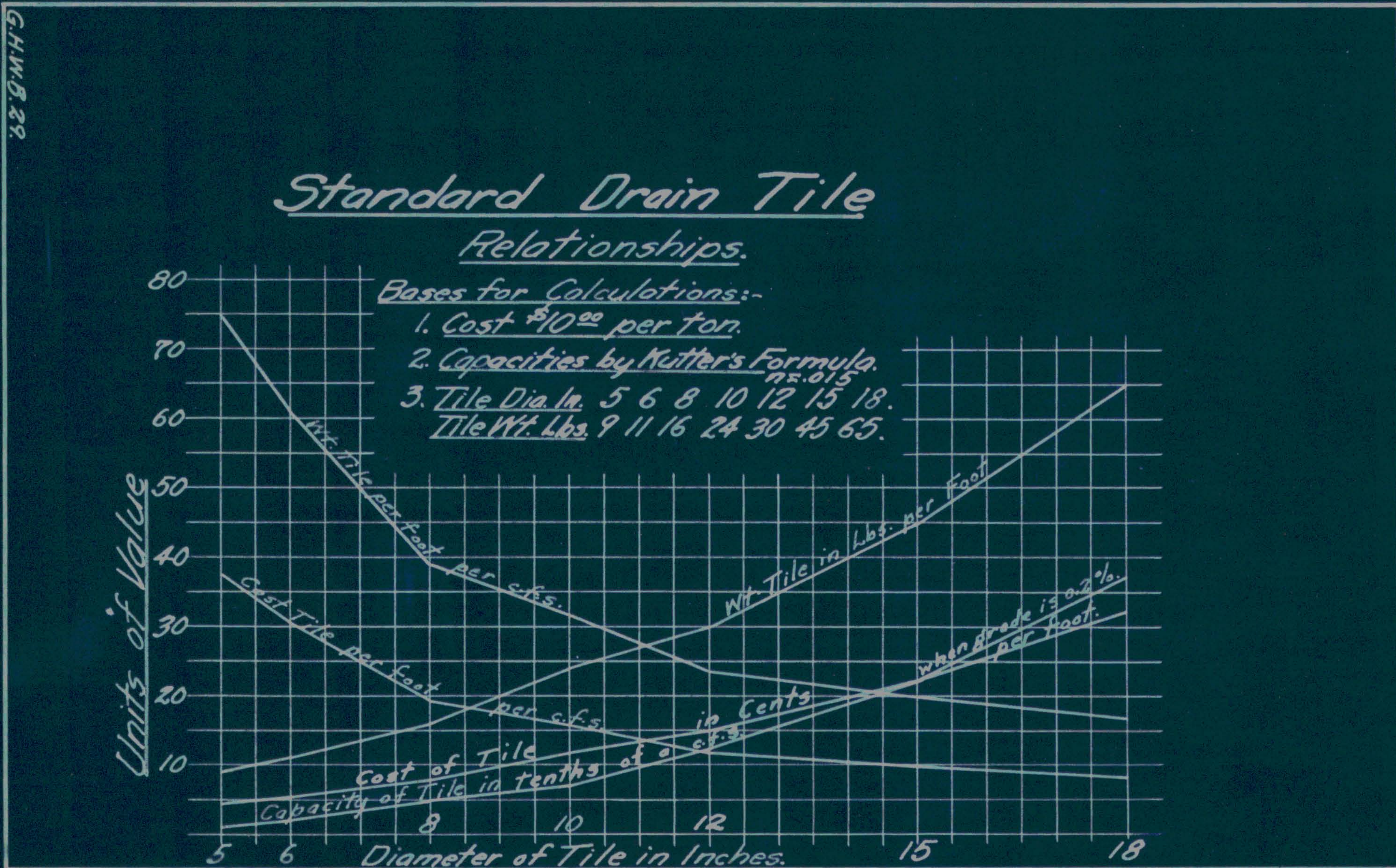
In the installation of a drainage system, it should be borne in mind that the improvement is presumed to be permanent, and that after tile is once covered up, it is more expensive to uncover it and replace it with larger tile than to install a new drain, so it is false economy to cut down on the size of tile. It is much better err on the side of too great capacity than too small capacity.

The smaller sizes of tile should be given a grade of not less than 2 feet per 1000 feet and a steeper grade is desirable. The larger sizes of tile may be laid on a minimum grade of half as much or less, if extreme care is used in construction. Upper limits are not so well defined, but it is not likely that unusually steep grades will be encountered except where lines must run down the slope of a pali. Under such a condition, joints should be cemented or a continuous pipe should be employed.

CONSTRUCTION METHODS

The usual method of constructing furrows for irrigation in the Territory should suffice ofor the construction of furrows for surface drainage. If grading of the soil between furrows is necessary, blade graders may be found serviceable. In the construction of field laterals, much hand labor will be found feasible. It is only in the case of main and sub-main drains that excavating machinery will be likely to find a place. For this purpose, shovels or dragline excavators will be found most suitable. Proper attention should be paid to the maintenance of line and grade and proper side-slopes should be afforded.

It is not likely that open drains will be employed to any great extent for underdrainage, but where it is found necessary, the use of teams and scrapers rarely will be feasible, hand labor will prove expensive and unsatisfactory, and the use of machinery will involve injury to crops in most instances. On the whole, the use of small drag-line excavators proves most satisfactory for such work. Operations should commence at the outlet of each line and proceed up the slope. Ample side slopes should be provided and a berm should be left


G.H.W.B. 29.
Standard Drain Tile
Relationships.
Bases for Calculations:-
1. Cost $10.00 per ton.
2. Capacities by Kutter's Formula. n=.015
3. Tile Dia. In. 5 6 8 10 12 15 18.
Tile Wt. Lbs. 9 11 16 24 30 45 65.
Wt. Tile per foot per c.f.s.
Cost Tile per foot per c.f.s.
Wt. Tile in Lbs. per Foot
Cost of Tile in Cents
Capacity of Tile in tenths of a c.f.s. when grade is 0.2% per foot.
Units of Value
80
70
60
50
40
30
20
10
5
6
8
10
12
15
18
Diameter of Tile in Inches.

sufficiently wide to permit the passage of the machine subsequently for maintenance purposes. The spoil may be piled on either or both sides and may be used to keep surface water from entering the drain. The minimum bottom width for such a drain is about 4 feet. The accompanying figures illustrate a drag-line excavator and a drain constructed by a machine. (Figs. 14 and 15.)

Drain lines must be laid out carefully and grade stakes set. The complete drain must be true to grade and as straight as possible. For open ditch work, center line and slope stakes should be set. For machine trenching a single line of stakes will suffice. For hand trenching, it is advisable to stretch a cord on the ground along one side of the proposed trench, to obtain good alignment. To insure accurate grade at all points, grade planks should be set up at each station at a uniform height above the grade of the drain, as shown in the accompanying figure. (Fig. 16). A stout cord may then be stretched over the middle line of the trench, from plank to plank, and every point on this cord will be at the given height above grade. Grade may be established at one end of each tile with a grade pole having a length equal to the distance from the cord to the proper location of the tile. This may be accomplished by keeping the cord taut by suspending a tile or other weight at each end, and measuring down from the cord at the desired points.

Construction work should always be started at the outlet of each line and proceed up the slope, so that the water developed will drain away. Surface water should be kept out of the drain during construction.

In installing covered drains, either hand labor or trenching machinery may be employed. Frequently, on small projects, hand trenching

Fig. 14.

Drag-line Excavator.

Fig. 15.

Open Drain Constructed with Above Excavator.

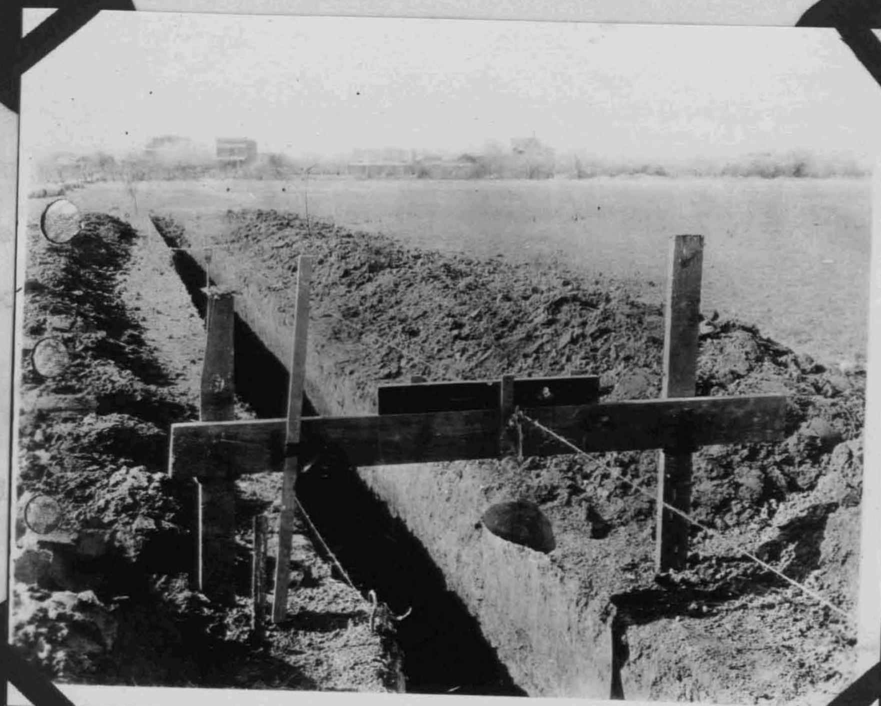


Fig. 16.

Illustrating Use of Grade Planks and Cord in Hand Trenching.

is cheaper, but usually on larger projects machines can do the work more rapidly, economically and satisfactorily. Generally it is preferable to let a contract for the work to an experienced and able contractor. A type of trenching machine suitable for the drainage of either humid or irrigated soils is shown in the accompanying figure. (Fig. 17).

If hand labor is used, it often is necessary to operate with small gangs, ordinarily about a half-dozen men to a line, since the trench should be opened from top to bottom as rapidly as may be, and the tile be laid and blinded before caving can take place. The men should work as closely together as practicable, and, if there is danger of caving, not even the first spading should be taken more than a rod in advance of the tile laying. The man removing the last spading also should grade the bottom of the trench. If the soil is fluxible, he should not step on the finished bottom and no one should stand near the edge of the trench, nor should wagons or material of any sort be permitted near the trench. No irrigation should be carried on near the trench and no irrigation of the tract should be done for a considerable period before construction work is undertaken. The soil removed from the trench should be placed as far back as it conveniently may be. The tile should be laid at once and be blinded by means of a few inches of earth caved from the edges of the trench. If the banks tend to cave off in large chunks or slabs, it will be necessary to brace them apart by means of planks separated by stout cross pieces or trench jacks.

A very troublesome condition is that in which the presence of a wet, pervious stratum near the bottom of the trench causes a lateral and upward movement of the soil at the bottom of the trench. In such a case, it is necessary to provide a tight cribbing to shut out the

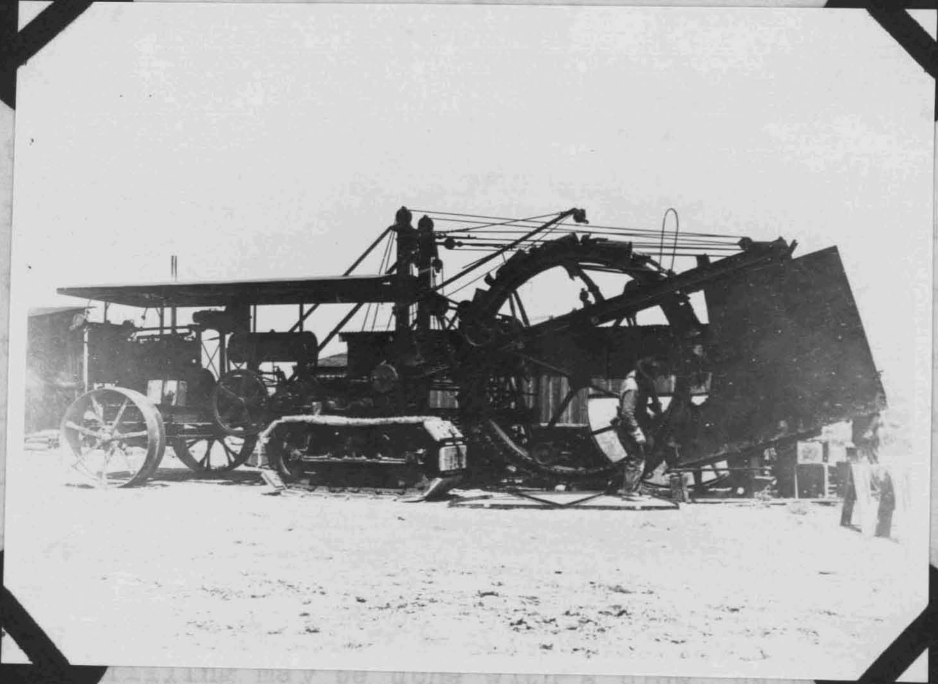


Fig. 17.

Trenching Machine Provided with Shield.

oozing material.

If the soil in the bottom of the completed trench is so soft that it will not support a man's weight, wooden racks of cradles should be laid under the tile to kpep it in line and on the grade. If conditions are exceedingly bad, it often is advisable to use sewer pipe instead of drain tile, as the bells aid in keeping the line intact.

Tile should be laid with extreme care. The joints should be as tight as possible, and if the soil is semi-fluid and contains much fine sand and silt, it will be necessary to provide some means of keeping oozing material from entering the tile joints. Almost all of the water entering tile lines makes its way through the joints, practically none entering through the walls of even the most porous tile, so the covering for the joints must provide for the ready passage of the water. Graded gravel, ranging in size from coarse sand to pebbles an inch in diameter, makes an excellent filter. Cinders are satisfactory, also. Wide strips of heavy roofing material should be wrapped around the joints first. The more pervious material excavated from the trench should be placed adjacent to the tile.

The backfilling may be done with a plow, using three or more animals and a long pole evener, or with a scraper, road grader or "V" crowder. Power backfillers are avail able also, for the larger projects. All of the excavated material should be returned to the trench and be banked up over it, so that future settling will not leave a depression over the drain.

Surface water should be kept away from the backfilled trench, for several years as a rule, and ditches should be carried across the trench by means of flumes. In the case of the irrigated plantations, the furrows will cross the tile lines at sharp angles. It will be impossible to keep the water in the furrows away from the drains and amd for this reason exceptional care must be exercised in laying in the drain, protecting the joints and restoring the backfill. It may be necessary, to tamp the backfill after the blinding material has been placed.

DEVICES.

Bulkheads and Outfalls.

The outlet of a drainage system should come in for more consideration than usually is given to it. If the tile line discharges into a deep channel, at some distance above the water lever, an outfall should be provided. This may consist of a corrugated iron pipe extending far enough out over the bank to discharge the drainage water directly into the stream without striking the bank and causing erosion. The other end should be anchored by means of a concrete wall, and a careful connection with the tile line must be made so that the water will not find its way along the outside of the conduit. The last few joints between tile should be cemented.

If the drain discharges at or near the water level or bottom of a channel, such an outfall may be provided or a concrete, masonry or timber bulkhead should be constructed to prevent injury from the caving of the banks, and to prevent the washing out of the tile line at the lower end. Care should be taken that it has a good foundation in order that it may not be undermined. A network of copper, galvanized iron or monel metal wires or rods should be placed across the outlet to keep out small animals. Fish sould not be screened out, however, as their presence is advantageous.

If the drain discharges directly into the sea, extraordinary precaution must be used in the protection of the outlet. An automatic gate or breastwall will be advantageous in preventing the rush of waves up the drain line.

Manholes

If the subsoil in which covered drains are laid is fluxible, a manhold should be installed at a change in direction of a major drain line and at important junctions. If the soil contains much fine sand, a combination manhole and sand trap should be located at such points, as well as at every change from a steep to a lighter grade. Such a device serves asan observation well in which the flow may be seen and the general conditions of the system be watched. It also serves as a settling basin for any sand or silt that may be carried by the drain, and if the trap be made to extend a foot or two below the grade of the drain, a chamber is formed in which a considerable amount of silt may be held until it can be removed. A manhole may be provided with a surface inlet to make it possible to take care of surface water and, if desired, to provide for flusing out the drain. As a manhole proper, it provides a means for the operation of a root-cutting and drain-cleaning device, operated by sewer rods. If it is expected that such work will be necessary, the drains should be laid out in straight lines with grades as uniform as possible, and a manhole should be provided at each junction, change in slope from a steep to a lighter grade, and on straight sections, at intervals of not to exceed 500 feet.

On straight lines a manhole may be made long and narrow, but at a junction or turn it should be made circular or square to facilitate the operation of rods. The most suitable type is built up of sections of corrugated iron, as shown in the accompanying figure. (Fig. 18). Brick, concrete or lumber also may be used. When built of lumber, 20inch material should be employed and the structure shoud be framed

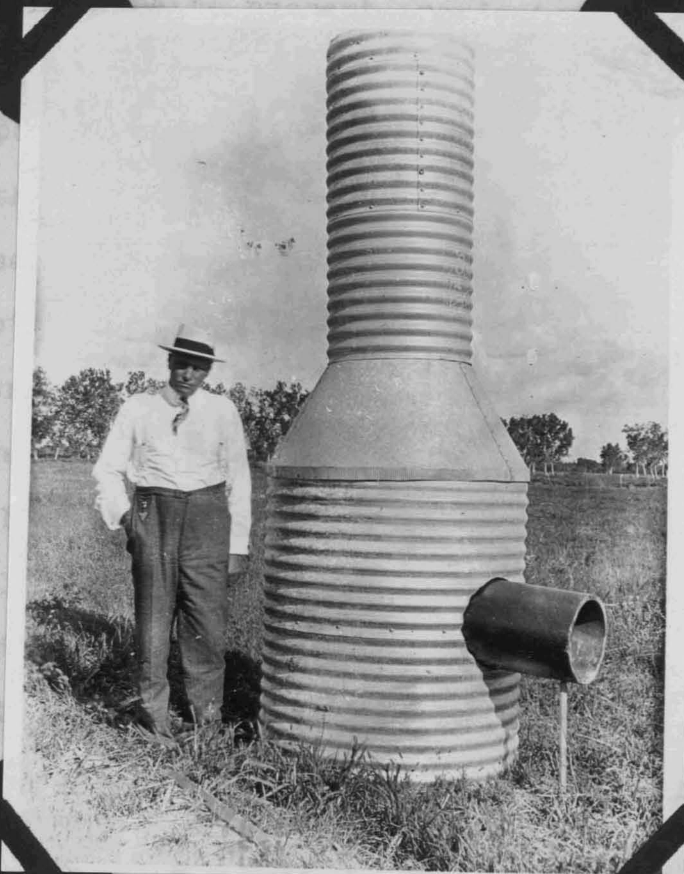


Fig. 18.

Corrugated Iron Manhole.

so its integrity of form will not depend upon the durability of the nails. In any case a cover should be provided which may be locked down, and in some soils it is necessary to provide a bottom.

Observation Wells.

If little sand be present, rendering the use of sand traps unnecessary, it sometimes is desirable to provide for observation of the flow at points throughout the system. Nothing serves this purpose better than a vertical length of corrugated iron pipe or stack of large-sized sewer pipe, extending from a little above the ground surface to a foot or more below the tile line, and having holes cut near the lower end to accomodate the drain tile which project slightly through the wall. A small settling space is provided, from which sediment may be removed by means of a bent shovel or telephone spoon. A cover should be provided and joints between sewer pipe should be cemented. This device costs little and occupies small space and should be placed at turns and junctions of minor drain lines and may also be installed between manholes for inspection purposes, by using a "T" section at the lower end connected in the drain line.

Surface Inlets and Flushing Wells.

A vertical stack of pipe is useful also as a surface inlet or flushing well. The bottom should be cemented and the top should be provided with a grating and a mound of gravel or crushed stone. Joints should be cemented and the backfill should be well compacted around the stack. Such an inlet should be installed wherever a drain crosses a depression or flat, so that waste water or storm water may not pond long enough to puddle the soil or injure the crop. During irrigation, the entrance of water may be prevented by trhowing up a circular ridge of earth around the mound. Such a device should be used, also, at the upper end of each branch line. The first few lengths of tile in the drain should be a size larger than the tile designed for the drain, so that loss of head on entry will be reduced. Manholes, observation wells and flushing wells are necessary only where the subsoil is fluxible.

Relief Wells.

The source of damaging water often is in some deep, pervious stratum and its movement is upward. The stratum is connected with a higher lying source of supply and the water is under pressure. Ordinary methods of drainage avail little, since the damaging water rises between drains, however closely they may be spaced, and it is not unusual to find water standing on the ground surface within ten feet of a drain six feet or more in depth. The source of the water may be in gravel, sandstone, sand, shale, coral or lava. A pressure condition has been found, even, where the only change in subsoil conditions was in the nature of the clay strata.

To meet the conditions, it is necessary to install relief wells connecting the pervious stratum with a tile drain laid at ordinary depth. The pressure causes the water to rise through the relief wells, which act as vertical drains. The sole purpose of the ordinary drain is to carry off the water brought up by the relief wells, and it accomplishes little, or no direct drainage. With the pressure relieved at the drain level, the damaging water can no longer make its way to the ground surface within the area affected by the wells. It is necessary in each case to determine the required number and spacing of the wells and the best indication is the effect of one well upon another. A vertical stack of sewer pipe or an iron pipe may be used for casing a relief well. The casings should be connected carefully to the drain line, so there will be no danger of the wells silting up during periods of inactivity.

Flumes.

Flumes should be provided for all canals and ditches that cross underdrains. They should be water-tight and should extend well across the trenches in either direction.

Flumes must be used also for carrying the water of canals and ditches across open drains. In some cases inverted siphons are necessary. Such flumes or siphons should extend well into either bank and should be provided with bulkheads having converging and diverging wing walls and cut-off apron walls.

Bridges.

Farm and road bridges of good design and careful construction will be required in the case of open drains.

Surface Inlets for Open Drains.

Storm and waste water must be conveyed into open drains through properly constructed drops, flumes, chutes or pipes. Great care must be used in the design of the structures at the points of entry and discharge to avoid erosion of the channel or disturbance of the flow of the drain and to guard against the water making its way under or around the structure and eroding the canal banks. There are many types of inlets in use.

SUBSEQUENT TREATMENT.

It must be borne in mind that underdrainage is only the basis for reclamation of waterlogged or saline lands; that drainage alone often is ineffective for complete reclamation, and that subsequent treatment is necessary. The physical condition of such soils is certain to be poor, the humus content unlikely to be normal, and there may be an excess of harmful saline materials present. Humus must be restored, salts must be removed, evaporation must be reduced so that the future rise of salts may be prevented, aeration must be enhanced and the tilth of the soil must be improved. The usual cultural operations will be of importance, the burning of cane or trash will aid in the flocculation of the soil and the addition of cane wastes and press cake will be advantageous.

If expedition be desired in the removal of salts, or if natural precipitation and irrigation are insufficient to effect a satisfactory reduction in the percentage, a copious application of irrigation water should be applied to the land and allowed to percolate through the soil as rapidly as possible. In no case should an attempt be made to flush the salts from the surface. They must be leached out and carried downward in solution to the underground reservoir. Normally it is recommended that the land be diked into checks and that the water be ponded as deeply as feasible, each check having an area as large as the slope of the ground and the amount of available water will permit. The desirability of using large checks and liberal quantities of water is due to the fact that capillary attraction is effective in all directions and it is necessary to offset the tendency of the salts to move laterally in the soil and reappear on a higher or dryer portion of the tract. For this reason it is required to make sure, in flooding, that all the surface is covered, even if knolls and ridges must be leveled first. It will be seen that the Hawaiian furrow system of irrigation does not lend itself very well to the process of leaching, since there will be a tendency for the salts to be leached out of the furrows and to be translocated to the intervening ridges. It may be, however, that if leaching is done during periods of low evaporatinn, using very large quantities of water, and if the ridges be protected by means of trash, it will not be necessary to level down the ridges.

The amount of salts removed by leaching process depends upon the amount of water moving through the salt-impregnated soil, upon the amount of salts in the soil, upon the solubility of the salts, upon the structure of the soil, upon the quality of the leaching water and upon a number of other factors.

The amount of water moving through a given soil will vary somewhat with the amount of the supply. If a very light application be made, the surface soil may be moistened and the capillary film may be thickened for a few inches in depth only, with the result that subsequent evaporation will remove more moisture than was applied, with a consequential increase in the accumulation of saline materials. If a somewhat heavier application be made, the capillary film may be thickened throughout the root zone but, without a definite further downward movement, no salts will be removed and the result is likely to be a further concentration of salts within the root zone and on the ground surface. With a still heavier application, a gravitational movement of the capillary water may be set up and some salts may be removed from the root zone. Satisfactory results will not be obtained, unless a sufficiently heavy application of water be made to overcharge the soil pores and set up a gravitational movement of free water.

Much of the same reasoning may be applied to a consideration of the practices involved in the use of slightly saline irrigation water.

With respect to the structure of the soil, two aspects are of special importance. First, salts are contained largely in the capillary spaces of the soil, while leaching water moves more freely through any cracks, burrows or other non-capillary openings that may exist in the soil, and this conditions presents an additional reason for overe charging the natural drainage capacity of the soil. Second, if the soil structure is so compact that the water moves very slowly through it, there is danger that the salt movement may be reversed. Under such conditions, it is necessary to put the soil into the most receptive state, impound the water by levees to increase its head, and apply the leaching process at times of least evaporation. Early cultivation of the leached soil is of advantage, and the use of artificial mulches may be necessary. The greatest difficulty is likely to be experienced in the case of highly colloidal soils which expand greatly upon waiting. Such soils abound in the Territory.

With respect to the quality of the leaching water, it is evident that "sweet" water will be more effective than saline water, not only because of the greater solubility, but because of the fact that there is no contribution of salts to offset.

Coming now to the point of the two methods of leaching out salts, or preventing their accumulation, by the application of excessive amount of water, either periodically or at each irrigation, it may be said that the end to be attained is to keep up a downward movement of the soil water, and to prevent its upward movement and subsequent evaporation from the surface. If the ground water table is well below the root zone, and the drainage is good, no particular difficulty should be experienced in the application of either method. With a high water table, either permanent or temporary, primary or perched, extreme care must be used. With poor natural drainage, either method might prove disastrous, and even if good artificial drainage has been provided, there is a possibility of seriously overcharging the drainage capacity of the soil itself. Indeed, in the application of very large quantities of water at certain periods, the natural result would be the overcharging of the drainage capacity of the soil for a period and the success of the process would depend upon a rapid lowering of the water table to a normal position beyond the capillary reach before the upward movement of the salt-laden water could cause a concentration on the ground surface and in the root zone. In the application of the other method, there should be no marked rise of the ground water table and, consequently, no subsequent critical period. A further advantage of the continual application of an excessive amount of water is that the demand for water would be more uniform, which is of importance, particularly in the case of pumped water. On the other hand, an advantage of the periodic application of very large quantities of water is that such application may be made at times of lower normal demand. A further advantage is that such application may be made at times of lower rate of evaporation. These periods are usually coincident under island conditions.

It is of importance to consider the effect of the leaching process upon the supply of plant fertility. The elements of the latter being soluble, such beneficial substances are leached out along with the harmful salts. Indeed, sodium nitrate is leached out in greater proportion than any of the harmful salts. Moreover, the bacterial production of nitric nitrogen in the soil is retarded under conditions of excessive moisture content and poor aeration. It would require extensive investigation to determine the relative advantages and disadvantages of the two methods in this respect. Finally, the method of application of fertilizer has an important bearing o n the subject. Manifestly, where fertilizer is applied in the irrigation water, the advantage is with the method of using very large quantities of leaching water at certain periods, the fertilizer being applied at other times, care being used that the water shall not percolate beyond the root zone during the latter periods.

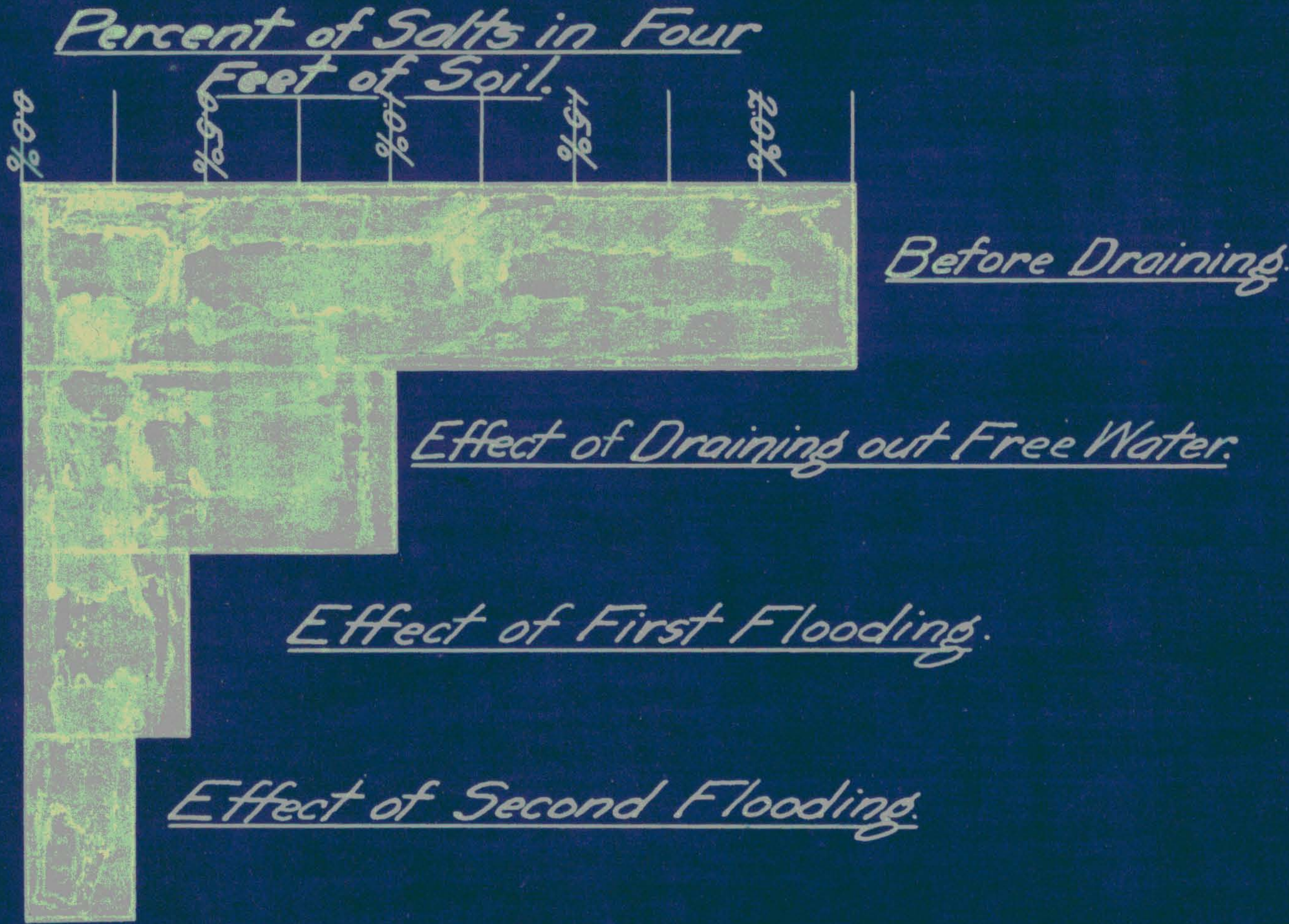
The accompanying diagram (Fig. 19) illustrates an actual case of reclamation of salt-impregnated soil on the mainland. Before drainage, the average salt content in the first four feet of soil was 2.25%. Removal of the excess water already in the soil reduced the percentage to 1.00%, some of the salts being in solution. To effect the removal of the salts accumulated on the ground surface, and further to dilute the soil water, two floodings were given, As a result of the first, the average salt content was reduced to 0.43% and as a result of the second, the average was reduced to 0.28%. Natural precipitation and the melting of snow the following winter were responsible for a further reduction to about 0.20%, and excellent crops were produced the next year.

After proper leaching of the soil, sugar cane may be grown on the ridges, rather than in the furrows, and this will be of advantage where the depth to the ground water table is less than is desirable.

Example of Removal of Salts.

G.H.W. 8.28.

Fig 19



108

Where possible, land should be cultivated after leaching, and in any event it is desirable to obtain a crop cover as soon as possible. Artificial mulching of the surface may be necessary in some instances.

It has been pointed out, already, that, in the case of lands subjected to the heaviest rainfall, it may be necessary to provide an artificial covering to aid in shedding the excess water into the drainage furrows. The process of mulching with black roofing paper appears to be adaptable to this scheme. The use of a heavy grade of paper would be advantageous and it has been suggested that some experiments be conducted along this line. The following layouts have been proposed:

(1) Cane rows 4 feet apart, running more or less down the greatest slope, with furrows between adjacent rows, cut into the more stable sub-soil, the cane rows to be ridged up with the surplus soil and covered with a single strip of paper, with the cane projecting through its longitudinal axes, the paper being slit only sufficiently to supply the necessary moisture to the plant roots.

(2) Cane rows 4 feet apart, running more or less down the greatest slope, with furrows between alternate rows, cut into the more stable subsoil, and being somewhat larger than in the first case, with the surplus soil placed between cane rows and ridged up so that the plats slope both ways uniformly to the furrows, and being covered with two strips of paper, joined at the crest of the ridge and extending outside the cane rows, the paper being slit only so much as necessary.

(3) Like the second case, except using three strips of paper, two having cane projecting through along the longitudinal axis and

slit as before, but the third not slit and laid out over the ridge between cane rows and overlapping the first two strips.

Such a covering would not only aid in shedding surplus precipitation but would tend toward conservation of heat. It has been found that several factors have a bearing on the amount of heat absorbed and retained by the soil. These are as follows:

(1) Air temperature.
(2) Termperature of precipitated water,
(3) Angle of the rays of the sun.
(4) Percentage and intensity of sunshine.
(5) Direction and degree of slope of the ground as related to the direction of the rays of the sun.
(6) Moisture content of the soil.
(7) Evaporation of moisture from the soil.
(8) Character of the soil.
(9) Physical condition of the soil.
(10) Color of the soil or its artificial covering.
(11) Nature of the crop or mulch.

Manifestly we can exercise no control over items 1,2,3, and 4, and our control over item 5 is somewhat limited. However, we can control the moisture content of the soil and also the evaporation of moisture, to a considerable extent. We may change the character of the soil somewhat, and we exercise a measure of control over its physical condition. We cannot change the color of the soil appreciably, as a matter of practice, but we may do as we please in the matter of the color of an artificial covering. The nature of the crop is practically fixed and the nature of the mulch is of no concern if we provide a protective covering.

Experiments on the mainland have shown that the temperature of a soil with an artificial black covering was more than 13°F. higher than the same soil with an artificial white covering. Such a variation cannot be expected in the case of island soils, but the principal remains the same, and it would appear that the combined advantage of moisture control and heat conservation might make the use of paper covering feasible.

MAINTENANCE.

Open drains require almost constant maintenance if they are to be fully effective. The channel must be kept free from growths of moss and vegetation, and accumulation of silt, weeds and debris must be prevented. The smaller ditches will call for hand labor in maintenance but in the case of the larger ditches excavators provided with drag buckets or clam shell buckets will be found satisfactory.

If a closed underdrainage system be of proper design and construction the matter of maintenance is of small consequence. If silt has accumulated in the tile lines during construction they should be flushed out before the job is accepted.. Irregularities due to the uneven settling of the backfill should be corrected so that irrigation water will have no opportunity of making its way directly into a drain line. Vegetation that is likely to develop roots in the tile and obstruct the drains should be removed from the vicinity of the lines. Silt may continue to find its way into the tile lines for some time. This will be caught in the sand traps and should be removed from time to time.

In cases of serious obstruction of the tile by sediment or by the growth of roots, the conduit may be cleared with special cleaning devices, a number of which have been developed. These are very useful during construction, also, in keeping the suspended matter in motion near the point of laying until sufficient water is developed to carry the material along. After the system is put into operation, they may be used to clean out such roots as may have penetrated the tile through the joints or to clear the line of obstructions caused by sand or silt. One of these devices is in thenature of an auger, while another is built like a small hoe. For the removal of roots, an apparatus involving a spiral cutter is used, or better still, a sort of wire brush. The latter is useful also in removing other obstructions and may be made easily by wrapping a piece of belting around a cylindrical wooden rod, first having driven the belting full of nails of such length that the outside diameter of the completed brush is somewhat smaller than the inside diameter of the tile to be cleaned. A still simpler device, and one that has proved very satisfactory, is a bunch of barbed wire. These devices may be operated most conveniently by means of jointed sewer rods. The latter are made up in 3 or 4 foot sections, fitted with couplings so arranged that the rods may be joined when two sections are placed at right angles, and are locked together when the two sections are in line. Working in a manhole, a man can easily put together and operate several hundred feet of rod in a line.

The operation of drainage systems should be observed frequently by examination of the flow at the outlets and through manholes and observation wells, and if any portion becomes inactive it should be looked after at once.


SKETCH MAP of HOOLAU AREA.
Scale 1" = 600'
G.H.W.B. 26.
Longitudinal Profile
Ground Surface
Ditch
Ditch
H.T.
L.T.
Hundred Feet
Mauka Profile
Ground Surface
Water Table
H.T.
Lagoon
Levee
NORTH
KALUANUI
Plantation Ry.
Good Cane
Good Cane
Kaluanui Stream
KAPAKA
Road
Road
Mauka Profile
Longitudinal profile
Ditch
Ditch
Fair Cane
Rice Mill
Lagoon
PAPAAKOKO
Govt. Road
PACIFIC OCEAN

APPENDIX "A"

SUGGESTIONS FOR THE DRAINAGE OF THE PLANTATION

of

KOOLAU AGRICUTURAL COMPANY, LTD.

at

HAUULA, OAHU.

The plantation of the Koolau Agricultural Company, Ltd. is located at Hauula on the windward side of Oahu and occupies a rather narrow belt of comparatively flat land adjacent to the seashore, a belt of higher land of more considerable slope extending well up toward the foot of the precipitous Koolau Range, and several small areas extending back into the mouths of defiles.

The higher lands are devoted to the growing of sugar cane but the narrow belt of flat, low-lying land has been devoted, heretofore, largely to the growing of rice and taro, both of which are adapted to culture on lands generally excessively wet and having a relatively high water table.

With the culture of rice no longer commercially economic, it is desired to convert the area involved into cane land. The area in its present condition, however, is not suitable to the growing of sugar cane owing to the presence of a high water table and to the fact that the soil is often overcharged with water.

If reference be made to the accompanying map and profiles, an idea of the topography of the area under consideration may be had. A natural levee of coral sand skirts the seashore. This levee rises to a height of between 7 and 8 feet above mean sea level. It has been improved artificially and its crest is occupied by the Government road which circles the island. Just mauka of the levee the normal ground surface has an average elevation of about 2 feet above mean high tide, but the uniformity of the surface is broken by several channels extending toward the sea and a land-locked lagoon extending about parallel to the seashore for a distance of nearly a thousand feet. The average bottom elevation of this lagoon is not far from mean high tide and its lowest elevation is practically at mean sea level. Water stands in the lagoon constantly. The largest channel extending toward the sea is that of Kaluanui Stream and it has an unobstructed gravity outlet to the sea, while a channel near the south end of the lagoon has been provided with a box culvert under the Government road, the outer end of which is provided with a gate which may be closed by hand during the period of high tide. The bottom of this culvert is located practically at mean low tide. At times the outlet of the culvert is completely buried in sand washed up at high tide.

It will be noted on the mauka profile that the ground slopes downward for several hundred feet mauka from the edge of the lagoon, then slopes upward, ever increasingly, until the foot of a low pali is reached. At this point there is a rather sudden rise of about 12 feet, while the slope above the brow of the pali is rather moderate.

The width of the area from the levee to the foot of the steeper slope varies from about 1000 feet to a third of a mile. Practically all of this area is too wet for the successful growing of sugar cane. Good cane is being grown, however, on the slightly higher ground just mauka of the lagoon and also on land at the northern end of the plantation. Soil borings indicated depths to the ground water table of from 2 to 3 feet in these localities.

It is practically impossible to make a general statement regarding the soil of the area. It is largely transported soil, derived from the basaltic lava of the Koolau Range but modified by intermixture with coral sand. Lava rocks, pebbles and black sand also are found in the soil. As would be expected, the coral sand predominates nearer the seashore and the tighter soil predominates at greater distances from the seashore. In some cases the subsoil near the seashore is almost clear coral sand, often rather coarse and generally very permeable. In general the subsoil near the upper edge of the area is not so permeable. This is very fortunate from the standpoint of drainage reclamation, since, were the conditions reversed, lateral seepage from higher lands would be of much greater consequence and drainage design would need to take cognizance of the fact.

Not only is the present rooting depth of the soil too shallow and the moisture content too high, but the soil no doubt, is in a poor physical condition due to its poorly drained condition, its temperature likely is too low, and the nitric nitrogen content probably is insufficient to support cane production. Drainage, in addition to improving the moisture condition of the soil, will provide better aeration and will tend to warm the soil. Subsequent treatment will be necessary, however, to improve the tilth of the soil and to establish proper conditions respecting plant fertility.

Irrigation of sugar cane will be neccary and this will involve changes in the present layout of the irrigation system. The design of a drainage system respecting layout will depend, to a considerable degree, on the layout of the irrigation system. The latter layout should have some regard for the needs of drainage, so it will be well to design the two systems in correlation.

No rainfall data are available for the plantation itself, but very complete data are available for Kahuku Plantation which is located about 7 miles to the northwest. From some comparative records and general observations, it appears that the normal precipitation is greater on the Koolau Plantation than on Kahuku Plantation and that heavier storms occur.

The following table of precipitation data was made up of records from the U. S. Weather Bureau:

PRECIPITATION DATA FOR KAHUKU

MONTH	1913	1914	1915	1916	1917	1918	1919	1920	1921	NORMAL
Jan.	2.72	3.29	----	16.62	11.45	8.51	2.17	3.10	11.18	4.16
Feb.	3.45	1.38	----	1.67	2.67	5.84	0.71	1.19	1.47	5.22
Mar.	2.95	7.41	----	4.40	15.50	6.14	2.20	9.61	2.62	5.07
Apr.	1.30	3.01	0.63	1.93	2.39	16.56	3.12	2.13	1.78	2.82
May	2.72	2.60	0.40	2.78	1.67	1.67	1.02	1.45	1.69	2.01
Jun.	6.21	0.90	2.80	0.59	4.15	1.17	1.36	1.47	0.46	1.60
Jul.	0.91	3.92	4.24	2.46	1.02	1.81	1.96	3.60	1.67	1.80
Aug.	2.49	1.76	1.79	1.96	1.20	3.88	0.87	2.65	1.10	2.32
Sep.	1.41	6.17	1.24	1.82	2.43	1.62	3.27	2.35	1.34	2.27
Oct.	3.00	1.19	2.56	2.67	1.50	2.07	2.46	2.14	2.16	2.51
Nov.	3.08	0123	6.05	4.10	3.61	10.21	1.05	1.60	0.65	3.90
Dec.	1.07	5.56	8.06	6.08	5.45	3.85	2.83	7.78	3.40	4.11
Ann.	31.31	37.72	----	47.08	52.84	63.33	23.02	39.07	29.52	37.79

MAXIMUM RAINFALL IN 24 HOURS

YEAR	MONTH	AMOUNT	YEAR	MONTH	AMOUNT	YEAR	MONTH	AMOUNT
1905	Sep.	3.19	1911	May	2.27	1917	Mar.	4.30
1906	Nov.	3.10	1912	Jan.	1.55	1918	Apr.	6.05
1907	Dec.	2.70	1913	Jun.	4.31	1919	Apr.	1.73
1908	Mar.	3.65	1914	Dec.	3.65	1920	Dec.	2.62
1909	Mar.	9.57	1915	Apr.	7.50	1921	Jan.	2.10
1910	Nov.	2.25	1916	Jan.	4.10	MEAN	----	3.80

DATA FOR MARCH 1909

DAY	AMOUNT	DAY	AMOUNT	DAY	AMOUNT	DAY	AMOUNT
1	0.07	9	0.15	17	0.08	25	0.02
2	0.10	10	0.50	18	0.24	26	0.03
3	0.16	11	0.02	19	0.13	27	0.02
4	0.15	12	2.25	20	0.14	28	0.04
5	0.01	13	9.57	21	0.02	29	0.06
6	0.01	14	0.00	22	0.02	30	0.02
7	0.01	15	0.68	23	0.12	31	0.01
8	0.01	16	0.04	24	0.02	T.	14.70

Total for storm of 12-13 - - - 11.82"
Total for week 12-18 - - - - - 12.86"
Average per day for week 12-18 1.84"

The ground water table just mauka from the levee has an elevation practically at mean high tide, from which it follows that the natural underdrainage capacity of the soil is rather limited and that a large proportion of the excess water reaching the soil must contribute to surface run-off. With the installation of a proper underdrainage system, the ground water table generally would be lowered, but it still would be necessary to provide drainage capa city for a large proportion of the excess water reaching the soil. The lack of natural underdrainage facilities will require also that practically all of the deep percolation losses from irrigation must be taken care of by artificial underdrainage.

As has been pointed out the rainfall on the plantation is higher than that at Kahuku, The rainfall on higher portions of the plantation is higher also than that on the wet area itself, while the rainfall on the adjacent mountain slopes is very high. Outside surface run-off may be diverted from the wet area, but seepage from the higher land will continue to reach the wet area and must be intercepted and disposed of by the drainage system.

It has been pointed out in the general report that a minimum depth of 4 feet should be provided wherever possible. Such depth is not available for the lower lying lands of the Koolau Plantation, with gravity outlet. To afford the requisite depth, it would be necessary to resort to tide gate control or pumping. The former method does not appear to be feasible, owing to the small range and the fact that the necessary unit drainage capacity is unusually large. It would be necessary to provide sufficient outlet capacity so that the gate would operate only for a short time at low tide and even then a portion of the land could not be drained to the requisite depth. Direct discharge into the sea would be necessary and this would require a very expensive structure, the cost of which would not be warranted by the area involved in the project. It appears necessary therefore, to resort to pumping, and such process seems to be feasible, particularly if the pumped water be used, at least at times, in the irrigation of a portion of the plantation.

In the layout of a drainage system it will be essential that the storm water from outside the wet area be segregated from that to be taken care of by underdrainage system and the pumping plant. Kaluanui Stream and the stream near the southern end of the area should be preserved as storm waste-ways. Their outlets to the sea should be unimpeded and their channels should be unobstructed. If need be, levees should be built upon their banks to prevent overflow into the wet area. Storm water, originating above the railroad should be diverted into these channels by means of open, intercepting ditches. If these ditches be given a depth somewhat greater than is customary, they will serve the additional useful purpose of intercepting a portion of the subsurface seepage from the higher land. It will be well to leave the ditch at the northern end of the wet area in its present position, but its channel should be improved and deepened somewhat.

The logical position for the pumping plant is at the northern end of the lagoon, Provision should be made to discharge the pumped water into Kaluanui Stream just mauka of the Government road, through a discharge pipe as short as may be. The outlet of the discharge pipe should be below extreme low tide level, in order that advantage may be taken of the siphon effect at times of low water. The pump sump should be sunk several feet below the grade of the main drain. It may be lined with concrete on sides and bottom. A centrifugal pump should be employed. The pump should be driven by means of an electric motor, direct connected, unless the pumping head for irrigation is considerably in excess of that for drainage only. An automatic float control should be provided so that the pump will operate only as required. A flap gate should be installed in the discharge pipe to protect the plant from reversed flow at high tide during any period of inoperation. The equipment should be well housed.

The design for capacity of the pumping plant should be generous since automatic control is to be afforded. It appears that if a run-off of 1 inch in 24 hours is provided for, all but the most exceptional storm will be taken care of within a reasonable time. It would be out of the question to provide for maximum conditions, but it may be feasible to employ a higher rate than suggested.

The main drain should be an open canal, extending from the pumping plant southerly through the lagoon, past the rice mill, thence through the lowest ground mauka of the storm channel near the

Papaakoko boundary to a point about 400 feet from that boundary. It should have a depth at the pumping plant such that the bottom of the channel will be one or two feet below mean low tide. A somewhat greater depth would be desirable from the standpoint of drainage solely, but if the drainage water is to be used for irrigation, it would not be safe to have the drain too deep so near the shore line. The grade of the main drain should be practically flat. This will require a larger cross-section than usual and it may be desirable to provide an even larger cross-section in order that some storage capacity will be afforded.. Ordinarily the depth of flow should not exceed one foot. Fall is not avaiable to secure a velocity of flow in excess of one-half foot per second. This would require a minimum bottom width of about 10 feet. It would be advisable to provide a greater width to afford a factor of safety and some measure of storage capacity. Side slopes should not be flatter than 2 to 1 for that portion of the drain which is located in sandy soil.. The waste material should be used to fill in the lagoon and other especially low places.

An open sub-main drain should be located just mauka of the fair cane adjacent to the lagoon. It should extend northerly, thence turn toward and join the main drain near the pumping plant. This drain should be given a very flat grade and all possible depth. It may be much smaller than the main drain, but should have flat side slopes.

The minor natural channels should be connected with the main drain and their outlet to the sea should be closed to prevent tide water making its way back into the drainage system.

Intercepting tile drains should be located at the foot of the low pali heretofore mentioned and, in general, at the change in slope from a steep to a lighter grade at or near the upper edge of the wet area. These intercepting lines should be given a depth of 6 or 7 feet or more as indicated by soil borings. The tile should cut through pervious material and bed on more stable material wherever possible. A grade of not less than 2 feet per 1000 feet should be given. This will necessitate the location of the intercepting lines as a series of "Y" forms, having short arms extending practically along contours, and conducting lines running more or less directly down the slope.

For the interior drainage, a network of tile lines having a depth of not less than 4 feet should be provided. These drains must be located with respect to the irrigation layout as indicated in the general report. It is likely that level ditches will be located about 300 feet apart and this should prove a satisfactory spacing for the drains located just up the slope from level ditches. The spacing of conducting drains will depend upon the spacing of the watercourses and straight ditches. Tile submains, connecting the conducting drains with the open main and sub-main drains, should occupy the lower portions of the area.

Intercepting drains and level drains should be of 6-inch tile. The size of tile for conducting drains and sub-main drains will depend upon the available slope and contributing areas and will probably range from 8-inch to 12-inch in diameter. It will likely be sufficient to provide for a run-off of 1 inch in 24 hours. The features of design are discussed in detail in the general report.

While the project is small, its reclamation is highly important and, owing to its importance, may warrant a higher unit expenditure than normally would be the case. It is recommended that a system be designed and cost estimates be secured and, if these demonstrate the project to be economical, that its construction be undertaken.

APPENDIX "B"

SUGGESTIONS FOR THE DRAINAGE OF THE LAIE PLANTATION

at

LAIE, OAHU.

The need for drainage on the Laie Plantation is acute with respect to a very small area, occupying a depression not far above sea level. Ditches already installed indicate that entirely satisfactory drainage depth cannot be obtained without resort to tide control or pumping.

No tide data are available for the windward side of Oahu, but at Honolulu the mean range is only 1.2 feet and the spring range is only 1.8 feet. The Kauai ratio is 0.8, so it is certain that the Honolulu figures are liberal if not representative.

It has been pointed out in the general report that, with such ranges, tide control is out of the question.

It appears that the area involved would not warrant the installation of a pumping system, both on account of the high initial cost and the necessity for more or less attendance in operation.

For the present, therefore, it is recommended that all possible depth be afforded to the existing ditches; that they be given flat grade, since sufficient grade to prevent growth of vegetation is not available, and that any necessary lateral open ditches be constructed. The use of tile, with a gravity outlet, is out of the question.

If results at Hauula seem to warrant, it may be feasible to provide a pumping system later, in which event, tile should be employed wherever possible. The feasibility of pumping may hinge on the practicability of using the pumped drainage water in irrigation.

"APPENDIX C".

SUGGESTIONS FOR THE DRAINAGE OF KAHUKU PLANTATION.

at

Kahuku, Oahu.

The Kahuku Plantation is located on the windward side of Oahu and extends both west and south from the northern extremity of the island. It comprises a body of relatively low land some little distance back from the shore line, separated from the sea by a higher coral formation; a body of land extending up the floodplain of an intermittent stream near the southern end of the plantation; a body of land occupying the slopes of the fan extending seaward from the northern extremity of the Koolau Range, and a body of land occupying the ridges and plateaus of the fan.

Sugar cane is being grown successfully on the slopes and top of the fan and in certain portions of the lower land, but results are not satisfactory over a considerable portion of the low area due to excessive moisture and a high water table. Conditions are particularly bad in Fields #2-a, #2b, #3-a, #3-b, a low cove in Field #4, a large part of Field #5, and in upper and lower Field #7, as well as in certain areas operated by individuals as tenants at will.

The investigations disclosed the fact that much of the low area, not in an apparent serious condition, would be improved greatly by drainage and that increased tonnage and improved quality ratio likely would render such reclamation feasible.

A half-dozen storm ditches leading from the mountains enter the plantations. A wasteway to the sea has been provided for several of these near the southern end of the plantation, the artificial channel being cut nearly to sea level. A wooden flap-gate has been provided to prevent water making its way back into the field ditches of Field #5 during periods of heavy storm run-off.

Other storm ditches find an outlet in a pond near the mill at Kahuku and an artificial channel has been cut through the coral reef to the sea so that the water level in the pond is maintained at an elevation slightly above mean sea level.

A storm ditch near the west end of the plantation finds an outlet in a puka in the coral formation not far from the water's edge.

The discharge of other ditches is dissipated over low wet areas lying behind an exceptionally wide belt of the coral formation skirting the sea-shore.

The particularly wet areas extend over a total distance of between 5 and 6 miles and comprise several separate units, in-so-far as drainage is concerned. It appears that Field #5 and the low cove of Field #4 constitute a unit and may be drained out through the artificial channel near the southern end of the Plantation. Fields #3-a and #3-b and the wet area at the extreme western end of the plantation appear to constitute a unit and may be drained to the puka above mentioned. Fields #2-a and #2-b and lands adjacent to Sano's pond, as well as the pond itself, constitute a unit and may be drained out through the artificial channel already provided. The upper part of Field #7 might also be joined to this unit. Field #7 and the land now occupied by tenants at will, as well as lands lying between Field #7 and the right-of-way of the Oahu Railway and Land Company comprise a unit for which there is no present outlet.

The necessity for treating the area in several units is indicated by the following elevation data of the railway line which traverses the area from Kahuku westward:

STATION	ELEVATION	REMARKS.
3719 + 51.6	5.8'	Terminus at Kahuku
3688	0.5'	Bottom of Sano's pond
3670	7.0'	Edge of pond
3661	8.0'	Subgrade coincident
3653	11.0'	High point
3645 + 50	4.0'	Depression
3638	11.5'	High point
3620	3.0'	Depression
3613	8.5'	High Point
3602	3.5'	Depression
3598	3.0'	Culvert in depression
3595 + 30	9.0'	High point
3593	7.5'	Marconi station
3576 + 30	2.5'	Depression
3571	7.0'	High point
3557	3.0'	Marsh
3549	4.0'	Kahuku Ranch
3532	12.0'	High point
3525	6.0'	Ditch from #3-b is 2'deeper
3518	4.0'	North of #3-b

Kahuku Ranch also separates the western end from the remainder of the Plantation.

As is indicated by the foregoing data, much of the land in need of drainage has an elevation only slightly above mean sea level so that gravity drainage is out of the question, and resort must be had to pumping, tidal-gate control being infeasible owing to the slight range of tidal variation.

It will be desirable to convey the storm water from higher lands across the area requiring drainage so that only the surplus water applied by precipitation and irrigation upon such area, and the subsurface seepage into such area, will need to be pumped.

This may be done by preserving and improving the present storm ditches near the southern and western ends of the plantation; diverting the storm ditches now discharging into Sano's pond into a channel skirting the pond or crossing the pond between levees and by providing a surface channel from the wet area in the vicinity of Field #7 to the sea.

Any necessary surface ditches should be provided to divert surface water from higher sources into the several storm ditches; their channels should be put into proper condition; their banks should be protected against overflow, and if need be, their capacities should be increased by enlargement of cross-section.

To effect the drainage of the wet areas four or five pumping plants will be required. One of these likely would be located near the flap-gate already mentioned and would serve Field #5 and the low cove in Field #4. Another should be located near the outlet of Sano's pond and would serve to drain the pond itself and the surrounding wet land, Fields #2-a and #2-b and, perhaps, a portion of upper Field #7 and of that held as tenancies at will. A third plant should be located adjacent to the storm ditch leading to the puka near the western end of the plantation and adjacent to the right-of-way of the Oahu Railway and Land Company, in order to serve Fiels #3-a and #3-b and the wet area at the extreme western extremity of the plantation. A fourth plant should be located just above the coral belt, below Field #7 and adjacent to the proposed surface channel leading to the sea. A fifth plant might be required in the vicinity of Marconi station owing to the fact that a low area south of the station appears to be cut off from the low area northwest of the station, by a considerable ridge. The latter plants would serve Field #7 and the adjacent tenancies at will.

The discharge pipes from the several plants should be led over the embankments of the storm ditches. The outlets of the pipes should be well toward the bottom of the channels in order that advantage may be taken of the siphon effect at times of minimum flow. The pump sumps should be sunk several feet below the grade of the main drains leading to them. They may be lined with concrete on sides and bottom. Centrifugal pumps should be employed. The pumps should be driven by means of electric motors, direct connected, unless provision is to be made to use the pumped water for the irrigation of lands at considerable elevation. Automatic float control should be provided so that the pumps will operate only as required. Check valves should be installed in the discharge pipes to prevent reversed flow during periods of pump inactivity. The equipment should be well housed.

The design for capacity of the pumping plants should be generous since automatic control is to be afforded.

In most instances the drainage system will comprise main open drains; open or covered sub-main drains and covered lateral and sub-lateral drains. In such case, a main drain, having a fairly flat grade and ample cross section will lead to the pumping plant. Its design should be in accordance with the principles set forth in the general report. Its depth, and that of any submains and laterals should be such that a minimum depth of 4 feet will be afforded to the sublaterals. Main drains should occupy the lowest part of the given area. Sub-mains should occupy major ramifying depressions. Laterals should be located largely with respect to the location of straight ditches while the position of sub-laterals will be fixed largely by the position of level ditches as explained in the general report.

In some instances, intercepting drains will be necessary. This is particularly true of the upper portion of Field #7, the low cove in Field #4 and in Field #2-b. In each case the drain should be located at the change of slope from a steep to a lighter grade. Such drains, ordinarily, should have a depth of 6 feet or more.

The following table of precipitatinn data was made up of records from the U. S. Weather Bureau:

PRECIPITATION DATA FOR KAHUKU

MONTH	1913	1914	1915	1916	1917	1918	1919	1920	1921	NORMAL
Jan.	2.72	3.39	----	16.62	11.45	8.51	2.17	3.10	11.18	4.16
Feb.	3.45	1.38	----	1.67	2.67	5.84	0.71	1.19	1.47	5.22
Mar.	2.95	7.41	----	4.40	15.30	6.14	2.20	9.61	2.62	5.07
Apr.	1.30	3.01	9.63	1.93	2.39	16.56	3.12	2.13	1.78	2.82
May	2.72	2.60	0.40	2.78	1.67	1.67	1.02	1.45	1.69	2.01
Jun.	6.21	0.90	2.80	0.59	4.15	1.17	1.36	1.47	0.46	1.60
Jul.	0.91	3.92	4.24	2.46	1.02	1.81	1.96	3.60	1.67	1.80
Aug.	2.49	1.76	1.79	1.96	1.20	3.88	0.87	2.65	1.10	2.32
Sep.	1.41	6.17	1.24	1.82	2.43	1.62	3.27	2.35	1.34	2.27
Oct.	3.00	1.19	2.56	2.67	1.50	2.07	2.46	2.14	2.16	2.51
Nov.	3.08	0.23	6.05	4.10	3.61	10.21	1.05	1.60	0.65	3.90
Dec.	1.07	5.86	8.06	6.08	5.45	3.85	2.83	7.78	3.40	4.11
Ann.	31.31	37.72	----	47.08	52.84	63.33	23.02	39.07	29.52	37.79

MAXIMUM RAINFALL IN 24 HOURS

YEAR	MONTH	AMOUNT	YEAR	MONTH	AMOUNT	YEAR	MONTH	AMOUNT
1905	Sep/	3.19	1911	May	2.27	1917	Mar.	4.30
1906	Nov.	3.10	1912	Jan.	1.55	1918	Apr.	6.05
1907	Dec.	2.70	1913	Jun.	4.31	1919	Apr.	1.75
1908	Mar.	3.65	1914	Dec.	3.65	1920	Dec.	2.62
1909	Mar.	9.57	1915	Apr.	7.50	1921	Jan.	2.10
1910	Nov.	2.25	1916	Jan.	4.10	MEAN	----	3.80

DATA FOR MARCH, 1909

DAY	AMOUNT	DAY	AMOUNT	DAY	AMOUNT	DAY	AMOUNT
1	0.07	9	0.15	17	0.08	25	0.02
2	0.10	10	0.50	18	0.24	26	0.03
3	0.16	11	0.02	19	0.13	27	0.02
4	0.15	12	2.25	20	0.14	28	0.04
5	0.01	13	9.57	21	0.02	29	0.06
6	0.01	14	0.00	22	0.02	30	0.02
7	0.01	15	0.68	23	0.12	31	0.01
8	0101	16	0.04	24	0.02	T.	14.70

Total for storm of 12-13 - - - 11.82"
Total for week 12-18 - - - - - 12.86"
Average per day for week 12-18 1.64"

It appears that if a run-off of 1 inch in 24 hours is provided for, all but the most exceptional storms will be taken care of within reasonable time, and that effective control of percolating irrigatinn water will be afforded. It is infeasible to provide for maximum conditions.

It is recommended that a topographic survey of the wet land and controlling areas be made; that a drainage system be designed and that an estimate of cost be obtained. If this demonstrates the project to be economical, its construction should be given serious consideration. It might be well to undertake the reclamation of one of the areas first as an experiment and a demonstration. Particular consideration should be given to the possibility of using the pumped drainage water for irrigation.

APPENDIX "D"

SUGGESTIONS FOR THE DRAINAGE OF EWA PLANTATION

at

EWA, OAHU.

Ewa Plantation is located on leeward Oahu near the southwest extremity of the island. It comprises land ranging in elevation from tide level near Hoaeae Station at the north end of West Loch of Pearl Harbor to mauka lands at an elevation of about 200 feet. Most of the plantation, however, is cut off from the sea by a coral formation, so a large proportion of the area is at some distance from the shore and at considerable elevation above sea level.

Many conditions of topography are presented and numerous soil types occur. The necessity for, or desirability of, artificial drainage has become apparent in a number of fields scattered over the plantation at various elevations, under various conditions of topography, and presenting various problems for solution.

The following table of precipitation data was made up of records from the U. S. Weather Bureau:

PRECIPITATION DATA FOR EWA.

MONTH	1913	1914	1915	1916	1917	1918	1919	1920	1921	NORMAL
Jan.	0.43	1.65	0.21	16.32	9.58	6.94	0.60	4.65	7.22	2.95
Feb.	0.83	1.32	0.21	4.82	2.15	3.35	0.00	0.37	1.67	4.10
Mar.	0.67	4.60	0.45	3.58	10.93	4.68	0.40	2.49	0.55	2.85
Apr.	0.50	0.85	1.28	1.66	1.24	7.63	0.37	0.72	0.21	1.11
May	0.08	1.08	0.35	0.56	1.79	0.24	0.46	0.60	0.26	0.91
Jun.	3.01	0.29	0.24	0.05	0.16	0.37	0.49	0.67	0.00	0.59
Jul.	0.53	0.51	0.86	0.48	0.42	0.02	0.16	0.48	0.21	0.39
Aug.	3.13	0.27	0.02	1.60	1.55	1.77	0.10	0.40	0.25	0.74
Sep.	1.04	2.12	1.87	0.55	1.05	0.79	0.99	0.00	0.40	1.04
Oct.	1.05	0.00	0.72	1.57	0.87	0.44	2.60	0.27	3.16	1.09
Nov.	1.47	1.21	6.52	0.55	1.39	6.38	1.34	0.86	0.20	2.81
Dec.	0.08	2.74	7.67	3.49	5.19	3.22	1.04	12.73	5.65	3.22
Ann.	15.82	16.64	20.40	35.23	36.32	35.83	8.55	24.24	19.78	21.80

MAXIMUM RAINFALL IN 24 HOURS

YEAR	MONTH	AMOUNT	YEAR	MONTH	AMOUNT	YEAR	MONTH	AMOUNT
1905	Aug.	1.90	1911	Feb.	2.84	1917	Mar.	8.15
1906	Dec.	3.38	1912	Apr.	1.05	1918	Nov.	3.41
1907	Jan.	3.49	1913	Aug.	2.42	1919	Oct.	2.42
1908	Mar.	5.18	1914	Mar.	2.30	1920	Dec.	9.47
1909	Jan.	2.35	1915	Nov.	3.56	1921	Dec.	2.53
1910	Dec.	2.96	1916	Jan.	4.45	MEAN	--	3.64

DATA FOR DECEMBER, 1920

DAY	AMOUNT	DAY	AMOUNT	DAY	AMOUNT	DAY	AMOUNT
1	---	9	0.07	17	---	25	---
2	---	10	---	18	---	26	---
3	---	11	---	19	---	27	---
4	---	12	1.10	20	---	28	---
5	0.09	13	0.17	21	---	29	---
6	---	14	---	22	0.25	30	---
7	0.08	15	---	23	9.47	31	---
8	0.08	16	---	24	1.42	T.	12.75

Total for storm of 22-24 - - - 11.14"

It will be seen from the foregoing data that the annual precipitation is so meager and its distribution over the year so unfavorable, that irrigation is essential. Irrigation is practiced generally over the plantation, the water being pumped from wells. The practice began about 1890 and has been developed until a maximum of over 91,000,000 gallons per day is being pumped. The heads vary from about 66 feet to about 215 feet, the source of the water generally being close to sea level.

The condition of excessive moisture content began to be apparent within three years after irrigation was first applied and spread until now fully a score of areas present a problem in drainage. These areas may be classified under five heads with respect to the problems of drainage, as follows:

(1) Land near tide level, as at Hoaeae Station.
(2) Land injured by seepage from reservoir, as in Field A.
(3) Land at foot of pali, injured by seepage, as in Field C.
(4) Land in an enclosed basin, as in Field #13-a
(5) Land injured as a result of restricted lateral movement of underground water, as in Field #11.

There are, of course, modifications and shadings of these fundamental problems, and some fields present a combination of two or more of them.

The field at Hoaeao Station has an elevation so little above sea level that gravity drainage is out of the question, and since the mean and spring ranges of tidal variations are only 1.2 feet and 1.8 feet respectively, tide-gate control is not feasible. Pumping offers the only recourse and it does not appear that such process would be economical on account of the small size of the unit. It will be well to obtain an estimate of cost of such reclamation in order better to decide the matter.

It appears that Field A may be drained by means of an intercepting line of drain, at least 6 feet deep, skirting the reservoir, with a conducting line leading to a suitable outlet. Perhaps a better arrangement would be to lay out the system in the shape of a "Y", the two arms serving as intercepting lines skirting the reservoir and the trunk line extending across the injured area. If necessary, other branches could be installed later.

Field C will require an intercepting drain located at the foot of the pali, approximately along a line at the change in slope from a steep to a lighter grade, and a conducting drain leading to a suitable outlet. The intercepting drain should have a depth of at least 6 feet. It may be necessary to install branch drains further down the slope to care for water applied directly to the tract itself.

The problem in Field #13-a (and #13-b) is complicated by the fact that the area occupies a sort of basin, being cut off from the sea by a higher coral formation, solid coral coming to the surface. A gravity outlet drain would need to be very long and would need to cut into the coral, so that the unit cost would be high for the acreage involved.

Pumping seems to offer the more feasible solution. Two outlets are available; one, the storm ditch adjacent to Field #13-b, which leads to the large puka in the coral formation; the other, the supply ditch leading toward the south. The chief advantage of the latter is that of conservation of water. The chief disadvantage is that it would be necessary to pump drainage water into the supply ditch, out of the irrigation season, so that a wasteway into the pasture lands, or to the sea, might have to be provided.

The layout and design of the required drainage system should be in accordance with the recommendations given in the general report.

The most suitable equipment for the pumping plant would be a centrifugal pump, direct connected to an electric motor, and provided with automatic float control. The pump should extend below the grade of the main drain and should be lined on the sides and bottom with concrete.

A system for Field #11 was designed at the time the field investigations were being made. No doubt this system has been installed and the proposed investigations are under way. It is expected that much will be learned from this experimental work which will be of value in the design of systems for the various units throughout the plantation.

Particular attention should be paid to the data on run-off. It appears that if a run-off of 3/4 inch in 24 hours is provided for, all but the most unusual storms will be taken care of, but it may prove feasible to employ a lower rate, say, 1/2 inch in 24 hours.

The desirability of leading the drainage water from wet areas into supply ditehes, wherever possible, is apparent. The question concerning the quality of such water has been discussed at length in the general report.

It is recommended that topographical surveys be made of all the wet areas and controlling areas and that drainage systems be designed and cost estimates be obtained. If these indicate that reclamation is economical, it should be undertaken.

APPENDIX "E"

SUGGESTIONS FOR THE DRAINING OF THE PLANTATION

of

KOLOA SUGAR COMPANY

at

KOLOA, KAUAI.

The plantation of the Koloa Sugar Company is located near the south extremity of Kauai and is exposed somewhat to both windward and kona storms with the result that the annual precipitation is much greater than on some windward plantations, and is fairly well distributed over the several months of the ye ar as may be seen from an examination of the precipitation data presented herewith.

Notwithstanding the relative high precipitation and its favorable distribution over the year, irrigation is necessary, and this fact must be taken into consideration in the design of a drainage system.

The following table of precipitation data was made up of records from the U. S. Weather Bureau:

PRECIPITATION DATA FOR MAHAULEPU

MONTH	1913	1914	1915	1916	1917	1918	1919	1920	1921	NORMAL
Jan.	1.34	5.93	0.62	15.75	7.09	7.02	2.31	11.29	38.51	6.49
Feb.	5.91	2.15	3.40	4.40	5.11	7.03	0.71	1.14	1.52	3.91
Mar.	3.69	5.01	1.14	6.50	10.13	15.67	2.76	6.61	4.97	7.15
Apr.	3.91	6.67	6.27	2.78	4.28	17.48	7.25	3.14	2.94	4.83
May.	6.26	13.86	1.08	6.66	3.72	2.64	2.88	3.12	1.45	4.32
Jun.	7.59	6.65	4.64	3.62	2.63	2.13	1.17	2.34	3.61	3.52
Jul.	3.05	4.70	3.41	3.88	4.39	5.18	4.77	4.07	4.04	3.69
Aug.	3.51	3.61	3.76	3.56	3.48	4.74	3.04	5.61	2.36	4.32
Sep.	2.93	27.77	8.81	2.19	2.99	1.32	2.19	5.11	2.90	5.09
Oct.	4.40	2.59	7.18	5.16	3.28	4.64	8.14	8.17	2.97	3.94
Nov.	11.90	2.87	8.50	9.86	3.93	6.70	1.29	6.71	2.94	5.74
Dec.	2.24	6.22	15.43	11.00	3.48	7.42	11.24	11.49	17.95	6.51
Ann.	x56.79	88.03	64.24	75.36	54.51	81.97	47.75	68.80	86.16	59.51

x(Does not check with total for months)

MAXIMUM RAINFALL IN 24 HOURS (KOLOA)

YEAR	MONTH	AMOUNT	YEAR	MONTH	AMOUNT	YEAR	MONTH	AMOUNT
1905	Nov.	6.25	1911	Jan.	3.41	1917	Apr.	4.00
1906	Aug.	2.36	1912	Nov.	1.11	1918	Apr.	5.20
1907	Jan.	8.00	1913	Jun.	4.68	1919	Oct.	3.57
1908	Mar.	4.03	1914	Sep.	6.02	1920	Jan.	4.03
1909	Mar.	6.00	1915	Dec.	4.30	1921	Jan.	10.30
1910	Nov.	7.91	1916	Jan.	3.23	MEAN	----	4.96

DATA FOR JANUARY 1921

Day	AMOUNT	DAY	AMOUNT	DAY	AMOUNT	DAY	AMOUNT
1	---	9	1.00	17	1.37	25	1.02
2	---	10	.33	18	1.28	26	.45
3	.47	11	.20	19	1.07	27	1.00
4	.92	12	.13	20	3.61	28	.40
5	.60	13	.55	21	.39	29	.01
6	1.56	14	1.79	22	.05	30	1.13
7	.67	15	3.51	23	.09	31	.42
8	1.57	16	10.30	24	---	T.	35.89

At Mahaulepu the following record was established.

DAY	AMOUNT	DAY	AMOUNT	DAY	AMOUNT	DAY	AMOUNT
1	---	9	.86	17	2.87	25	.66
2	---	10	.16	18	1.23	26	.34
3	.42	11	.36	19	1.48	27	.27
4	.70	12	.13	20	2.43	28	---
5	.25	13	.41	21	---	29	---
6	1.46	14	2.97	22	---	30	1.04
7	.36	15	2.63	23	---	31	.47
8	1.72	16	15.29	24	---	T.	38.51

Total for storm of 3-20 --- 35.73"
Total for week of 14-20 --- 28.90"

Average per day for week 14-20 --- 4.13"

In general, the plantation occupies relatively high land having favorable slopes but in the case of two areas water accumulates more rapidly than it is taken care of by natural processes. The most important area is Mahaulepu Field near the east end of the plantation, in which excessive moisture conditions obtain both as a result of surface run-off and seepage from higher lands. The other area is

Kaluahonu Field, nearer plantation headquarters, in which seepage from higher lands and retarded movement of applied water are chiefly responsible for an inhibitive moisture condition.

Originally, Mahaulepu Field appears to have been a natural swamp, but the system of storm ditches has served to dispose of most of the surface water. The field is a basin, in the nature of a bottle, being constricted makai, with an outcrop of lava across the neck. There is ample fall to the sea below this outcrop, to provide for gravity drainage and the fall in the field itself appears to be satisfactory for artificial drainage purposes.

The present system of storm ditches finds an outlet to the sea through a cut in the lava outcrop and could be deepened only at considerable expense. Furthermore, a diversion dam has been installed across the main ditch near Puukeke, for the irrigation of lower lands, and it is important that there be no interference with this structure.

Finally, it is desirable to keep the necessary underdrainage system separate from the storm ditch system in so far as possible, since maximum storm run-off is likely to occur coincidently with the greatest need for free underdrainage discharge.

If possible, the main outlet drain of the underdrainage system should join the main storm ditch at or a little above the diversion dam, and at such depth that the flow in the drain will not be impeded at times of maximum storm discharge. If this is not possible, it will be necessary to afford the drain greater depth and carry its outlet to a point below the dam, which will necessitate excavation into the lava.

The main drain should traverse the lowest part of the area and likely will need to be an open canal, in the interest of conservation of available fall. If open, the drain may be given a fall of 1 foot per mile or less. If a large tile is used, a fall not less than 5 feet per mile whould be afforded.

Several sub-mains will be required. These should occupy the more important ramifying depressions and should be covered tile drains if the available fall will warrant. The exact location and depth of the main and sub-mains can by determined only after a topographical survey of the area has been made. Other features of design should follow the recommendations presented in the general report.

Laterals and sub-laterals should be covered tile drains. Their location will depend largely upon the layout of the irrigated system. Under the proposed plan to install the orchard system of irrigation, it appears feasible to locate sub-laterals just up the slope from level ditches and to provide conducting drains running down the slope near adjacent or alternate straight ditches, as the conditions of the topography may require. Reference to the general report should be made in connection with the various features of design. It appears that intercepting lines will be required in several parts of the field.

A drainage run-off of 1 inch in 24 hours will serve to take care of all but the most exceptional storms.

The problems in Kaluahonu Field are much simpler than those of Mahaulepu, but in general will respond to the same treatment. Conditions appear favorable to the installation of a covered system throughout. The main drain should be so located that the developed water may be recovered for use in irrigation of lower lands. The design for capacity may be less generous, and the location of drains may be fitted to the irrigation system.

It is recommended that the work in Mahaulepu Field be undertaken first. A topographical survey is essential. With the topographical data available and with the irrigation layout decided upon, a drainage system may be designed and a cost estimate obtained. If this demonstrates the project to be economical, it should be undertaken.

APPENDIX "F"

SUGGESTIONS FOR THE DRAINAGE OF THE PLANTATION

of

MAKEE SUGAR COMPANY

at

KEALIA, KAUAI.

The plantation of the Makee Sugar Company is located on windward Kauai and occupies both mauka lands and low lying lands near the sea. The two areas of particular concern are in Field #32 and Field #17-a, #17-b and #17-c.

The former is situated mauka of a relatively higher coral belt skirting the seashore south of Kapaa. The latter occupies a former bay at the mouth of Kealia Stream.

Examination of Field #32 showed that the top soil is very shallow, generally followed by coarse coral sand, devoid of humus, and that the ground water table stood at a depth of from less than 1 foot to about 1½ feet. The elevation of the tract is not far above sea level and gravity drainage to a depth suitable for the culture of cane is not possible.

The mean tide range is only 1 foot and the spring range is only 1.6 feet so tide gate control is not feasible. Drainage of the tract, therefore, would require pumping of the developed water, and in addition it would be necessary to divert storm water from higher lands, directly to the sea. It is the opinion of the writer that the area involved is too small to warrant the necessary expenditure.

It is recommended that the present ditch system be deepened at the outlet as much as practicable and be constructed on a flat grade, since sufficient grade to prevent growth of vegetation cannot be obtained in any event. The ditches should be provided with side slopes and additional laterals should be installed as occasion affords. To be effective, the ditches should be properly maintained.

Fields #17-a, #17-b and #17-c constitute a single unit so far as drainage is concerned. Their natural outlet is Kealia Stream but the available depth is not sufficient for proper underdrainage. Pumping, therefore, will be necessary, and appears to be warranted by the size and position of the field and the quality of the soil.

Storm water from outside sources should be segregated from the water incident to the area itself. The bank of the stream should be protected against overflow and the present open drain lying between Fields #17-a and #17-b should be maintained as a storm ditch to take care of water coming from the gulch northwest of Field #17-a.

It appears desirable to provide a separate channel for the drainage water and conditions seem favorable to locate such channel along the line of the present sewer north of the hotel and office building. This ditch should be cut practically to sea level.

The pumping plant may be located on the low ground, near the power line in Field #17-b. The sump should be of such depth that all of the land of the area may be drained into it. The sump should be lined with concrete on the sides and bottom. Provision should be made to carry the discharge pipe over the embankment of the outlet channel and its mouth should be slow so that advantage may be taken of the siphon effect at times of low water. A check valve should be installed in the discharge pipe.

The most suitable equipment would be a centrifugal pump, direct connected to an electric motor, provided with automatic float control . If the pumped water may be used for irrigation, it will tend toward making the project more feasible.

The drainage system likely will comprise several ramifying open main drains; open sub-main drains and covered lateral and sub-lateral drains. The location and spacing of the latter will depend in large measure upon the layout of the irrigation system. The lay-out of the mains and sub-mains can be determined only after a topographical survey of the area has been made. Other features of the design should be in accordance with the recommendations offered in the general report.

Intercepting drains should be installed at the upper edge of the wet area practically along the line at the change in slope from a steep to a lighter grade. Wherever possible such drains should have a depth of at least 6 feet.

The following table of precipitation data was made up of records from the U. S. Weather Bureau:

PRECIPITATION DATA FOR KEALIA

MONTH	1913	1914	1915	1916	1917	1918	1919	1920	1921	NORMAL
Jan.	0.73	4.16	0.00	7.28	6.31	6.72	1.63	8.70	22.04	4.00
Feb.	2.61	0.45	0.98	4.35	2.63	4.61	0.90	0.50	1.30	3.96
Mar.	4.39	5.16	0.55	5.78	15.41	10.75	0.43	5.16	3.50	6.81
Apr.	1.38	5.70	3.87	0.70	2.21	8.79	3.46	4.06	2.85	2.50
May	1.74	7.02	0.25	2.55	4.11	0.78	1.09	2.47	2.28	2.43
Jun.	3.88	2.71	2.61	1.84	2.21	1.69	1.54	1.67	2.37	1.92
Jul.	0.97	1.71	2.29	3.15	3.95	1.51	1.22	3.17	1.29	2.00
Aug.	1.39	1.02	1.82	1.76	1.23	4.49	0.92	3.50	1.01	1.97
Sep.	2.22	18.36	1.90	1.85	3.07	1.39	0.88	3.72	1.40	3.02
Oct.	1.93	1.35	2.79	1.60	3.39	1.75	3.80	2.74	4.34	3.16
Nov.	7.77	2.07	6.19	4.16	3.10	7.43	4.09	4.12	1.10	3.98
Dec.	2.04	6.26	14.77	9.15	1.34	4.73	5.76	7.87	8.17	5.06
Ann.	31.05	55.97	38.02	44.17	48.96	54.64	25.72	47.68	51.65	40.81

MAXIMUM RAINFALL IN 24 HOURS

YEAR	MONTH	AMOUNT	YEAR	MONTH	AMOUNT	YEAR	MONTH	AMOUNT
1905	Nov.	1.98	1911	Sep.	3.55	1917	Mar.	4.50
1906	Dec.	1.60	1912	Dec.	2.20	1918	Nov.	6.81
1907	Jan.	5.85	1913	Mar.	2.75	1919	Oct.	3.08
1908	Mar.	4.20	1914	Sep.	8.30	1920	Jan.	4.02
1909	Mar.	4.12	1915	Dec.	3.81	1921	Jan.	4.03
1910	Nov.	8.70	1916	Dec.	4.20	MEAN	---	4.33

DATA FOR NOVEMBER, 1910

DAY	AMOUNT	DAY	AMOUNT	DAY	AMOUNT	DAY	AMOUNT
1	---	9	---	17	---	25	.25
2	8.70	10	---	18	---	26	.24
3	.85	11	---	19	---	27	---
4	---	12	.65	20	---	28	---
5	---	13	---	21	---	29	---
6	---	14	---	22	---	30	.38
7	---	15	----	23	---	--	
8	---	16	---	24	---	T.	11.07

Total for storm of 2-3 --- 9.55"

From the foregoing data it appears that if provision for a run-off of 1 inch in 24 hours is made it will take care of all but the most exceptional storms.

A topographical survey should be made; a drainage system designed in accordance with the data so obtained, and a cost estimate made. If this demonstrates the profect to be feasible, it is recommended that the drainage work be undertaken.

APPENDIX "G"

SUGGESTIONS FOR THE DRAINAGE OF THE OLAA PLANTATION

at

OLAA, HAWAII.

The drainage problem on the Olaa Plantation has to do largely with the improvement of the natural surface drainage. There may be some need for underdrainage, where conditions are favorable. On much of the plantation the surface drainage problem presents so unusual aspects and its solution, as well as the solution of the problems of drainage of the minor areas above-mentioned, whould follow the suggestions offered in the general report.

In connection with the problem in some of the higher fields, however, a situation is presented, which requires special treatment and, because the counterpart of the situation has not appeared, heretofore, it is desirable that special experiments be undertaken before the suggested solution be applied on a large scale.

A dual problem of soil moisture control and soil temperature control is presented. Such control is concerned with the upper limit of permissible soil moisture content and with the lower limit of required temperature.

Fortunately the two aspects of the problem are related and a solution of the former aspect will, in considerable degree, satisfy the requirements of the latter.

The studies already made indicate that the mean annual rainfall at 17-mile is over 200 inches, which is of course excessive and that the area is subject to heavy storms, a precipitation as high as 21.4 inches in one day having been recorded in January, 1922. The average number of days per year having a precipitation of 0.01 inch or over is 301, which indicates a high percentage of cloudiness. With respect to air temperatures, it has been found that the mean annual temperature is discouragingly low being 66.1° F (1922) as compared with 73.6° F, at Olaa Mill and with 73.5°F as an average for twelve sugar plantations on Kauai, Oahu, Maui and Hawaii. The mean monthly temperatures in 1922 at 17-mile range from 62.5°F for February to 69° F for September. At Olaa Mill the mean monthly temperatures range from 70.0°F (Jan) to 76.0° (Sep.) and the range for the average of the above-mentioned twelve plantations is from 69.8° F for January to 76.8° F for September.

All plants are subject to certain critical temperatures, both as respect germination and growth. A sugar-producing plant is expecially susceptible to the status of the supply of heat and sunshine. So far as I have been able to determine, no work has been done in the Territory relating to heat unit requirements and critical temperatures. By making a careful analysis of data from a large number of the plantations, I have concluded that developement is unsatisfactory when the mean monthly temperature falls to 70°or below. The following table gives the mean monthly and annual temperatures2 for 17-mile (1922).

Jan. 63.5° F	May 65.0° F	Sep. 69.0°F	
Feb. 62.5° F	Jun. 67.8°F	Oct. 68.0°F	
Mar. 64.0° F	Jul. 68.5°F	Nov. 66.5°F	Annual 66.1°F
Apr. 65.5° F	Aug. 68.5°F	Dec. 64.5°F	

It will be seen that the mean monthly temperature never reaches 70° at 17-mile, and one naturally wonders why cane grows at all in the locality. The following table of mean maximum monthly and annual temperatures may serve to shed some light upon this point.

Jan.	69°F	May	70°F	Sep.	75°F	
Feb.	68°F	Jun.	74°F	Oct.	75°F	
Mar.	69°F	Jul.	75°F	Nov.	72°F	Annual 72°F
Apr.	71°F	Aug.	74°F	Dec.	72°F	

Maximum temperatures probably reached as high as 90° F and it might appear that such growth as is made is the result of heat unit contributed during certain portions of the day during some seven or eight months of the year. Small wonder, then, that cane growth and sugar content are relatively smaller than at Olaa Mill where the temperature conditions obtaining are as indicated in the following table:

	Mean	Max.		Mean	Max.		Mean	Max.
Jan.	70.0°F	80.2°F	May	72.5°F	81.6°F	Sep.	76.0°F	84.0°F
Feb.	70.5°F	80.8°F	Jun.	74.0°F	82.6°F	Oct.	75.5°F	83.9°F
Mar.	72.0°F	81.3°F	Jul.	75.5°F	83.2°F	Nov.	74.0°F	82.3°F
Apr.	72.5°F	80.8°F	Aug.	75.5°F	83.6°F	Dec.	73.0°F	81.5°F
			Ann.	73.6°F	82.1°F			

As for soil temperatures, within the rootzone, it is a characteristic of tropical soils, that the temperature is somewhere near constant at a point near the mean annual air temperature. The investigations made in Field #7 showed an average soil temperature within the root zone of 66°F as compared with a mean annual air temperature of 66.1°F for 1922.

With respect to air temperature, conditions must be accepted as Nature has provided them. It is not within our power to alter the percentage of cloudy days nor to raise the temperature of the air. With respect to the soil temperature, however, we may produce some modifications, artificially.

It was aacertained in the studies of Field #7, that there was a definite relation between soil moisture content and soil temperatures. This is indicated in the following table.

% of soil moisture	Temperature
400.0% (2nd foot)	64.4°F
376.2% (1st foot)	65.3°F
316.7% (ed foot)	68.0°F

This is due to the fact that the quantity of heat required to raise the temperature of water one degree is about twice that needed to change the temperature of dry soil the same amount. Moreover, where the factor of evaporation enters in, about twenty times as much heat is required.

Artificial modification may be effected in two ways, one by moisture control and the other by conserving the available heat supply, first by assisting the soil to absorb more heat and second, by eliminating loss of heat so far as possible.

The first control is correlated with the first factor of the dual problem at Olaa, that of control of the upper limit of soil moisture. The second control involves a number of physical phenomena.

Control of the upper limit of soil moisture, where precipitation is the source of supply, is usually effected by drainage, either by surface works, or underdrainage, or both.

For underdrainage to operate, it is required that the soil pores, within the operating zone, be completely saturated with water to a height above the proposed depth of drains. A water table, either primary or perched and permanent or temporary, is involved. Surface drainage, on the other hand, serves a preventative purpose, providing a ready means of escape of water as it falls and restricting the percol ation of water into the soil.

The examinations at Olaa indicated that conditions generally are not favorable to the operation of an underdrainage system. There are, of course, areas in which underdrainage is required and in which such a system will operate successfully, but the solution of the problems in these areas is simple and is of no concern in the present discussion. The real problem at Olaa has to do with the preventative measures suggested above.

It appears that the natural drainage capacity of the soil of upper Olaa are unusually good. The soil is largely residualand the depth to the underlying rock is rather slight. The aa lava is well broken up and the pahoehoe lava is well interspersed with contraction fissures. The soil itself has a most remarkable water holding capacity, ranging up to 400 % on the dry weight basis, with no free water. The permeability of the soil is likewise very exceptional.

The annual precipitation is so great, however, the amount of water falling at one time is so heavy, and the percentage of rainy days is so high, that the soil is constantly in a condition in which the optimum moisture content is exceeded.

It appears necessary to provide means for diverting aportion of the precipitation so that it may not percolate into and through the soil within the root zone. The process must be based on surfaceh drainage, but the conditions are so unusual that ordinary methods will not apply.

In general, suitable wasteways must be provided for each tract so that the excess precipitation falling upon the tract may be immediately removed and so that water from higher lands may traverse the tract in channels. From such wasteways, suitable laterals must be led to the various depressions and troughs in the tract. From such laterals, sub-laterals must be led, in complex network, to every portion of the cane plats. Finally, the topography of the plats themselves must be such as to insure that a considerable portion of the precipitations shall reach, and be eliminated by the drainage system and that but a proper portion of the precipitation be permitted to percolate into the soil.

The canerows should run down the steepest slope, in-so-far as possible, and it is a fortunate circumstance that the subsoil immediately underlying the surface soil is of such nature as to render this procedure feasible.

There is little out of the ordinary in the layout of the suggested system, but owing to the extreme absorptive capacity of the soil, the intensity of storms and the physical structure of the top soil which renders it subject to erosion, it appears desirable, if not necessary, to modify the usual system to the extent of artificially protecting the soil from direct precipitation and expediting the movement of water into the sub-laterals.

This brings us to a further consideration of the second factor in the dual problem - that of heat conservation.

It has been found that several factors have a bearing on the amount of heat aborbed and retained by the soil. These are as follows:-

(1) Air temperatures.

(2) Temperature of precipitated water.

(3) Angle of the rays of the sun.

(4) Percentage and intensity of sunshine.

(5) Direction and degree of slope of the ground as related to direction of the rays of the sun.

(6) Moisture content of soil.

(7) Evaporation of moisture from soil.

(8) Character of soil.

(9) Physical condition of soil.

(10) Color of soil (or artificial covering).

(11) Nature of crop or mulch.

Manifestly we can exert no control over items 1, 2, 3 and 4, and that our control of item 5 is somewhat limited. We can, however, control the moisture content of the soil and also the evaporation of moisture to considerable extent. We may change the character of the soil somewhat and we exercise a measure of control over its physical condition. We cannot change the color of the soil appreciably, as a matter of practice, but we may do as we please in the matter of the color of an artificial covering. The nature of the crop is practically fixed and the nature of the mulch is of no concern if we provide a protective covering.

Experiments have shown that (under mainland conditions) the temperature of a soil with an artificial black covering was more than 13° F higher than the same soil with an artificial white covering. Such a variation could not be expected in the case of Olaa soils but the principle remains the same.

The relation of soil moisture to soil temperature has already been pointed out. A protective covering would afford moisture control and, what is vastly more important, control of evaporation.

It would appear that the use of mulching paper so generally employed in the Territory is susceptible to adaptation to the present requirements and should prove ideal in most respects. I hope some experiments may be tried and I beg to suggest the following layouts:

First: Cane rows 4 feet apart. Rows running down greatest slope. Furrows between all cane rows, cut into reddish subsoil. Cane rows ridged up with surplus soil. Single strip of paper with cane projecting through longitudinal axis. Paper slit only sufficiently to supply necessary moisture to plant roots.

Second: Cane rows 4 feet apart. Rows running down greatest slope. Furrows between alternate cane rows, cut into reddist subsoil and larger than in the first example. Surplus soil placed between cane rows and ridged up so that plate slope both ways uniformly to the furrows. Two stips of paper, joined at crest of ridge and extending outside of cane rows. Paper slit only so much as necessary.

Third: Like second example except three strips of paper, two having cane projecting through along longitudinal axis and slit as before but the third laid out over ridge between cane rows and over-lapping the first two strips. The third strip is not to be slit.

Soil moisture, soil temperature, growth, yield, quality ratio run-off and other studies should be made. Comparative studies should be made on adjacent untreated plats and on some good field near Olaa Mill. The economic aspect is, of course, of prime importance and it will be necessary to keep accurate records of costs of all operations. Observations should also be made as to desirable slopes and cross-sections of furrows and ditches, erosion, weed growth, and other factors.

In conclusion it may be said that there is a serious question as to the feasibility of successfully growing sugar cane in the coldest portions of the Olaa Plantation and if the suggested plan does not work out economically, the situation does not appear very hopeful.

APPENDIX "H"

SUGGESTIONS FOR THE DRAINAGE OF THE PLANTATION

of

KEKAHA SUGAR COMPANY

at

KEKAHA, KAUAI.

The plantation of the Kekaha Sugar Company is located on leeward Kauai and extends well toward the western extremity of the island. Much of the cane land is high or has a slope favorable to good drainage but there is a considerable area of low land, lying behind a higher coral formation skirting the sea shore, which is too wet owing to accumulation of surface and seepage water.

The following data of rainfall were excerpted from the records of the U. S. Weather Bureau:

PRECIPITATION DATA FOR KEKAHA.

MONTH	1913	1914	1915	1916	1917	1918	1919	1920	1921	NORMAL
Jan.	1.25	2.62	0.20	7.76	7.55	5.14	T.	12.98	15.85	3.40
Feb.	1.57	0.64	0.04	3.23	3.85	3.69	T.	0.63	1.38	3.23
Mar.	T.	4.33	0.78	4.19	8.57	4.36	0.31	2.27	0.20	3.91
Apr.	0.23	0.96	1.03	1.59	3.44	5.23	T.	2.55	0.48	1.16
May	3.30	3.14	0.10	0.02	1.19	T.	0.18	2.15	1.15	1.07
Jun.	1.64	0.27	0.38	0.19	0.20	T.	0.60	1.40	0.15	0.35
Jul.	0.80	0.27	T.	0.21	0.43	0.11	0.35	0.96	0.00	0.40
Aug.	0.35	0.09	0.53	0.08	1.05	0.67	0.28	0.50	0.28	0.94
Sep.	0.74	2.42	0.47	0.20	0.49	0.37	2.41	0.28	0.10	1.29
Oct.	3.77	0.03	0.10	2.12	6.20	0.14	1.21	0.90	0.85	1.39
Nov.	2.80	1.12	2.03	2.06	0.53	4.45	1.78	0.67	T	2.45
Dec.	0.05	7.96	8.81	3.17	4.86	1.65	6.97	2.95	8.24	3.07
Ann.	16.50	30.85	14.47	24.82	38.36	25.81	14.09	28.24	28.69	22.66

MAXIMUM RAINFALL IN 24 HOURS

YEAR	MONTH	AMOUNT	YEAR	MONTH	AMOUNT	YEAR	MONTH	AMOUNT.
1905	Nov.	4.53	1911	Jan.	2.35	1917	Oct.	5.60
1906	Aug.	1.59	1912	Dec.	0.46	1918	Nov.	3.85
1907	Mar.	10.93	1913	Nov.	2.00	1919	Dec.	2.75
1908	Mar.	3.62	1914	Sep.	6.77	1920	Jan.	6.00
1909	Mar.	6.08	1915	Dec.	3.25	1921	Jan.	5.35
1910	Nov.	4.21	1916	Mar.	2.25	MEAN	----	4.21

DATA FOR MARCH 1907

DAY	AMOUNT	DAY	AMOUNT	DAY	AMOUNT	DAY	AMOUNT
1	2.42	9	----	17	----	25	----
2	10.93	10	----	18	----	26	----
3	----	11	----	19	----	27	----
4	----	12	----	20	----	28	----
5	0.27	13	----	21	----	29	----
6	1.30	14	T.	22	----	30	----
7	~~0000~~	15	----	23	----	31	----
8	----	16	----	24	----	T.	14.92

Total for storm of 1-2 - - 13.35"

Obviously irrigation is necessary owing both to the moderate total annual precipitation and to its distribution, and has an important bearing on the drainage problem. Furthermore, it is entirely feasible to use the developed drainage water for irrigation.

While the mean annual rainfall is moderate the maximum rainfall record shows that heavy storms occur. Indeed, the mean of the maximum daily rainfalls is higher than that at some of the windward plantations, and this fact must be taken into consideration in the design of a drainage system.

A considerable amount of drainage work has been done on the plantation and the results are very encouraging, indeed. In general, it appears that the management is on the right track, and it is the